

## ReMeMaRe Nursery and Aquaculture Feasibility Report

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## ReMeMaRe Nursery and Aquaculture Feasibility Report

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## Executive Summary

In England, recent centuries, have seen the loss of seagrass meadows from up to 50% of the water bodies where it was once found, 85% of saltmarsh and over 95% of native oyster reef. Restoring Meadow, Marsh and Reef (ReMeMaRe) (pronounced "re-memory"), is an ambitious habitat restoration initiative with a mission to restore *at least* 15% of these priority habitats along the English coast by 2043. In order to meet these targets there is anticipated to be a significant increase in the scale of restoration activities and projects being undertaken, which may require increased availability of sustainable saltmarsh, seagrass and oyster source material.

This study reviews the existing facilities, methods and processes for production of this source material and assesses the feasibility of upscaling to meet anticipated demand. This was done through a combination of desk study, questionnaires and telephone interviews with parties currently involved in the sector.

With regard to saltmarsh, currently the most commonly used practice for large-scale restoration is managed realignment or regulated tidal exchange. With the exception of a few projects, planting of saltmarsh is not regularly undertaken. There is potential that the demand for saltmarsh source material will increase if focus shifts to faster development of particular vegetative communities or if projects seek to restore habitat in areas where surrounding saltmarsh is absent. Unless a significant change in delivery strategy occurs, current commercial and small project-based nurseries are capable of meeting demand.

Conversely, substantial planting effort is undertaken for seagrass restoration and existing facilities are not capable of meeting the demand required to achieve restoration targets. Several different methods are currently employed in seagrass restoration, mostly at small scale, restoring a maximum of 1-2ha annually. The progressing research into upscaling restoration methods makes it difficult to determine the most appropriate facilities to enable large-scale restoration. The study presents scenarios for several different facilities to meet demand for restoration targets. At this time, investment in seed processing and storage facilities, is likely to provide the most economical means to upscaling. Using existing small-scale nurseries as a proxy, upscaling growth of seagrass plants for translocation will require significant financial investment but as methods improve this is likely to become a more feasible option. The study concluded that the most appropriate option would be one or more sites each combining multiple facilities for seagrass processing and production. The level of investment would be comparable with individual facilities and would enable adaptation as improved methods emerge.

Native oyster restoration is also undertaken by a variety of different methods and is complicated by the presence of disease that requires strict regulations on the movement of oysters between locations. The study found that establishment of a new hatchery would require significant investment and is unlikely to yield reliable output within the first few years of operation. Investment in existing facilities has the potential to reduce the investment required and the time to produce a reliable output but that is difficult to quantify at this stage. Existing commercial hatcheries, in theory, are able to meet the demand through provision of biosecure seed oyster, although increased communication between the restoration and commercial sector would be necessary to ensure availability of suitable stock over the desired timeframe. Spawning ponds are an established method of producing seed oyster or spat on shell and the results of the study suggests that these could be utilised on a regional basis to improve local availability of oyster.

While there is a feasible option to upscale production for each habitat type individually, the overall outcome of the study is the recommendation for a network of regional 'seascape hubs' incorporating facilities for all three habitats. Several of the facilities for individual habitats share the same requirements and therefore by creating a regional hub, the facilities could be shared and adapted as demand changes and new methods emerge. Significant investment would be required to establish each hub, however that risk is spread across all three habitat types and provides opportunity for research into combined production. Such sites are also expected to be more appealing, than individual habitat facilities, as education and outreach centres.

Several next steps and points for consideration are identified, including development of a central system for restoration projects to list their anticipated demand, aimed at improving communication and ensuring availability of restoration stock and identification of existing facilities and partners for collaboration.

### Key Points and Opportunities

In England, recent centuries have seen the loss of: 85% of saltmarsh; seagrass meadows from up to 50% of the waterbodies where it was previously found; and over 95% of native oyster reefs. The decline is such that active intervention is required to enable these habitats to recover to sustainable levels capable of providing nature-based solutions for resilience against climate change and biodiversity loss, and for improved health and wellbeing.

Current restoration practices in the UK do not create significant demand for saltmarsh nursery stock as large-scale planting is not widely undertaken.

Methods for successful large-scale seagrass restoration are currently subject to significant research efforts. Future restoration is likely to require a combination of seed-based and seedling/plant-based methods and substantial upscaling of facilities will be necessary to meet targets.

Establishment of new native oyster hatcheries with reliable output can be a lengthy process. Existing commercial oyster suppliers have the potential to meet the anticipated demand for restoration. Biosecurity of stock obtained from commercial oyster hatcheries that also process other species could be improved through changes in working practices and relatively minor investment in additional equipment to create separate systems.

Creation of a digital tool for tracking national saltmarsh, seagrass and oyster restoration demand could provide a useful tool for ensuring sufficient stock availability for restoration projects.

Efforts should be made to identify existing facilities or institutions willing to incorporate restoration facilities or identification of partners (commercial or research) who have interest in shared ownership of a facility.

Opportunities for circular economy exist and should be explored, such as the re-use of waste shell from the seafood market as cultch for restoration.

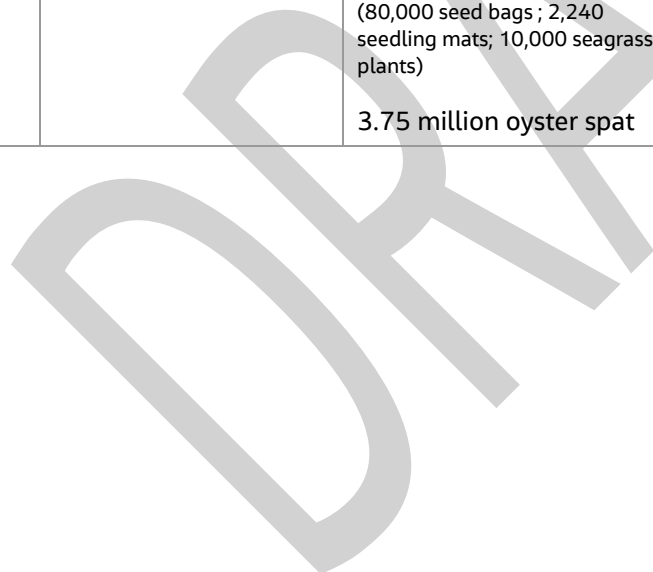
Coastal habitat restoration and associated facilities can contribute to a growing number of 'green jobs' in some of the most deprived areas in the UK.

Further research into the potential for multi-species aquaculture should be undertaken. Creation of a national network of 'seascape hubs' rather than individual nurseries and hatcheries would provide this opportunity. These hubs also present greater potential for inclusion of educational and outreach facilities.

Options explored for upscaling facilities for restoration

Habitat	ReMeMaRe 2043 Target	Facility Type	Estimated Annual Output	Annual Restoration	Rough Order of Magnitude Cost	Estimated FTEs
Saltmarsh	5325ha	Existing commercial supplier	Up to 2.8 million plants	46.7ha	n/a	n/a
		Project-based	<5,000 plants	<0.1ha	<£10,000	2
		Large-scale pond based	Up to 1 million plants	16.7ha	£260,500 - £612,500	20
Seagrass	550 – 600ha	Seed processing	20 million seeds (400,000 seed bags or 4 million DIS injections)	4 - 40ha	£189,675 - £442,575	10
		Lab-based seedling mats	1.5 million seeds (15,000 seedling mats)	37.5ha	£881,250 - £2.06 million	20 - 30
		Polytunnel-based seedling mats	1.5 million seeds (15,000 seedling mats)	37.5ha	£402,675 - £939,575	20 - 30
		Polytunnel-based plants	3.05 million seeds (183,000 plants)	36.6ha	£927,300 - £2.16 million	20 - 30
		Outdoor pond seedling mats	1.5 million seeds (15,000 seedling mats)	37.5ha	£153,750 - £358,750	10
		Combined seed processing and seedling/plant growth	10 million seeds (190,000 seed bags & 5,000 seedling mats)	14.5 – 33.5ha	£323,700 - £755,300	10 - 15

Habitat	ReMeMaRe 2043 Target	Facility Type	Estimated Annual Output	Annual Restoration	Rough Order of Magnitude Cost	Estimated FTEs
<b>Oyster</b>	100ha	Existing commercial supplier	More than 50 million spat	>50ha	n/a	n/a
		New hatchery	Up to 10 million spat	10ha	£292,500 - £682,500	5
		Spatting ponds	Up to 10 million spat	10ha	£390,000 - £910,000	5
		Investment in existing	Unknown	Unknown	Unknown	Unknown
<b>All</b>	5325ha saltmarsh 550 - 600ha seagrass 100ha oyster bed	Seascope Hub	978,000 saltmarsh plants 5 million seagrass seeds (80,000 seed bags ; 2,240 seedling mats; 10,000 seagrass plants) 3.75 million oyster spat	16.3ha saltmarsh 15ha seagrass 3.75ha oyster bed	£928,050 - £2.16 million	25 - 30



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## Acronyms and Abbreviations

BNG	Biodiversity Net Gain
BuDS	Buoy-Deployed Seeding
CIC	Community Interest Company
DEEP	Dornoch Environmental Enhancement Project
DIS	Dispenser Injection Seeding
eDNA	Environmental DNA
ENORI	Essex Native Oyster Restoration Initiative
FTE	Full Time Equivalent
FWC	Florida Fish and Wildlife Conservation Commission
GW	Gigawatt
IBC	Intermediate Bulk Container
LED	Light-emitting Diode
NMP	National Marine Park
NORA	Native Oyster Restoration Alliance
PAR	Photosynthetic Active Radiation
ppt	Parts Per Thousand
ReMeMaRe	Restoring Meadow, Marsh and Reef
ReMEDIES	Reducing and Mitigating Erosion and Disturbance Impacts affecting the Seabed
ROM	Rough Order of Magnitude
RYA	Royal Yachting Association
SAC	Special Area of Conservation
UV	Ultra violet
WWF	World Wildlife Fund
WWT	Wildfowl and Wetland Trust

## 1. Introduction

### 1.1 Background

Recent years have seen an increased focus on ecosystem services and habitat restoration, with the United Nations declaring a 'Decade on Ecosystem Restoration (2021-2030)'. Of particular focus are three priority coastal habitats; saltmarsh, seagrass and oyster reefs. These habitats provide resilience to coastlines and coastal species. In England, over recent centuries, have seen the loss of seagrass meadows from up to 50% of the water bodies where it was once found, 85% of saltmarsh and over 95% of native oyster reef<sup>1</sup>. Reasons for the initial decline in these habitats, some of which still hamper the successful restoration, include; land reclamation, habitat loss, introduction of disease or invasive species and anthropogenic damage or overfishing.

The benefits of coastal habitat restoration are well documented, not only the ecological benefits for associated species, but through provision of carbon sequestration, wave attenuation and flood defence, water quality improvements and social and cultural value. The restoration sector also provides a number of employment opportunities, which will increase with escalation of restoration efforts.

Restoring Meadow, Marsh and Reef (ReMeMaRe) (pronounced "re-memory"), is an ambitious estuarine and coastal restoration initiative which aims to address baseline shift and reverse centuries of decline with an initial focus on the three priority habitats that make up the acronym. The ReMeMaRe Vision is for restored estuarine and coastal habitats that benefit people and nature. The ReMeMaRe Mission is to restore *at least* 15% of our priority habitats along the English coast by 2043.

In order to implement this vision and achieve the mission, substantial upscaling in restoration projects will be necessary. For some of the target habitats a key factor in upscaling will be the ability to source restoration 'stock'. This can be supplied naturally from nearby populations or artificially introduced.

There are many considerations when obtaining stock for restoration.

- Pressure on donor populations - if stock is sourced from 'wild' populations by means other than natural spread, it can threaten the health and resilience of donor populations. Many wild populations are under existing pressure and therefore removal of individuals to supply restoration projects could result in negative impacts on those populations.
- Genetic configuration of populations - Many species have been shown to develop local adaptations which can be lost or diluted due to human intervention.
- Biosecurity - The movement of materials between different locations carries the inherent risk of introducing non-native and/or invasive species or pathogens with potential negative consequences for existing habitats and species.

Aquaculture and nursery facilities provide a means of obtaining source stock for restoration projects with a greater level of control over genetic configuration and biosecurity. Existing facilities in the UK specific to saltmarsh, seagrass and oyster are relatively limited and tend to be set up for a specific project and then presumably decommissioned or repurposed at the end of the project.

### 1.2 UK Plans and Policies

Restoration of saltmarsh, seagrass and oyster habitat and the facilities associated with this align with several UK plans and policies.

- Provision of natural wave attenuation and erosion control contributes to Shoreline Management Plans and protection against climate change.
- The Environment Act 2021 introduces legally binding environmental targets aimed at restoring natural habitats and increasing biodiversity. These include the requirement for Biodiversity Net Gain (BNG) which means that, from November 2023, developers will be required to take measures that provide habitat

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<sup>1</sup> <https://ecsa.international/reach/restoring-meadow-marsh-and-reef-rememare>

improvements relative to the pre-development conditions. Although this policy is applicable only down to Mean Low Water, it is anticipated that coastal habitat improvements or creation will result from any coastal development.

- The Defra 25 Year Environment Plan contains several goals to which saltmarsh, seagrass and oyster restoration are of relevance, namely: reversing the loss of marine biodiversity and, where practicable, restoring it; making sure populations of key species are sustainable with appropriate age structures; and ensuring seafloor habitats are productive and sufficiently extensive to support healthy, sustainable ecosystems.
- As part of the UK energy security strategy the Government has a target to deliver up to 50GW of offshore wind by 2030. In order to achieve this, they will 'introduce strategic compensation measures' which is likely to lead to an increase in large-scale coastal habitat restoration projects.
- Creation of jobs and opportunities associated with coastal habitat restoration aligns with the Levelling Up agenda, with a report published by the Green Alliance (2021) suggesting that areas coastal constituencies with historic or current seagrass habitats coincide with those with high labour risk, and therefore greatest benefit of job creation. Many habitat restoration projects include an educational element, with local outreach and making use of volunteers and citizen science.
- In recognition of increasing environmental responsibility, funding for environmental projects is being made at increasingly large-scale. Funds such as the Green Recovery Challenge Fund, Landscape Recovery Fund and the Natural Environment Investment Readiness Fund demonstrate the Government's commitment to achieve large-scale habitat restoration.

The need for restoration of saltmarsh, seagrass and oyster habitat is recognised globally and research into the most effective restoration methods is being undertaken in several countries by multiple organisations. Networks, collaborative working groups and information sharing forums have been established to ensure experiences and information can be shared. These include the UK Saltmarsh Specialist Forum, Global Seagrass Nursery Network, the Native Oyster Restoration Alliance (NORA) and the Native Oyster Network UK & Ireland. As part of this information sharing, ReMeMaRe has produced a number of guides and handbooks related to the restoration of saltmarsh, seagrass and oyster<sup>2</sup>.

### 1.3 Study Aims and Methods

This study reviews the existing utilisation of nursery and aquaculture facilities in the UK and internationally to support restoration of oyster, seagrass and saltmarsh habitats, and explores the requirement and feasibility of upscaling the current facilities to supply the growing number of restoration projects in England. The study utilised a combination of literature review, online questionnaire (Appendix A) and interviews with a variety of ReMeMaRe partners, restoration project personnel, researchers, nursery, aquaculture and shellfishery facilities managers and suppliers.

The questions were aimed at collecting information to determine:

- the reasons why individual projects chose to use nursery/aquaculture stock or particular life stages for restoration and therefore whether an increase in restoration projects will result in increased demand for aquaculture/nursery stock;
- the different types of facilities or set-ups that are currently used, their current output, and the relative cost;
- whether facilities can be adapted in response to some of the concerns that prohibit their use by restoration projects; and
- whether it is logistically and financially feasible to up-scale aquaculture/nursery facilities to supply the projected increase in restoration projects.

The costs presented in this report are Rough Order of Magnitude (ROM) estimates, based on the above questionnaire responses, desktop research and author's own best estimates. For each option, an ROM estimate has been developed for establishing a given facility, presented in the 75 - 175% range around the central estimate, in line with industry best practices. The number of FTEs and commentary around operating costs is also provided where possible. Operating costs are categorised as low, moderate or high based on energy demand and material requirements, such that a facility with little to no requirement to regulate the temperature and lighting or add material would have low costs, whereas a facility that requires temperature

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<sup>2</sup> <https://ecsa.international/reach/tools-and-guidance>

control, artificial lighting and significant input of materials would have high running costs. Further detail on the costs is provided in Appendix B.

## 1.4 Limitations

The information contained within this report is limited to that freely available or provided by participants in the study. Of the 40 organisations and individuals who were contacted, 15 provided inputs. There is potential for additional projects and nursery or aquaculture facilities to exist in the UK that have not been included in this report. Further consultation over a longer time period may have identified additional projects and facilities, especially those that are in the early stages of development. Additionally, the processes, success rates and estimated high-level costs are based upon the information available for a small number of facilities.

Restoration science is undergoing significant levels of research globally. The information and recommendations contained within this report are reflective of the current practises which may change in future as research progresses.

Due to the variation in rental values depending on location and property type, all ROM costs provided are based on purchase of land and building of facilities where appropriate.

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## 2. Saltmarsh

### 2.1 Saltmarsh Restoration Overview

Four methods of saltmarsh restoration/creation are currently undertaken in the UK:

- Protection/enhancement of existing saltmarsh
- Realigning defences
- Creation of urban fringe saltmarsh
- Planting

Protection or enhancement of existing saltmarsh is generally undertaken where existing saltmarsh has been degraded or is subject to erosion. In these cases, the approach is generally to make physical alterations to the site to improve drainage or sediment retention and then allow the saltmarsh to naturally recover under the improved conditions.

Most large-scale saltmarsh restoration projects consist of managed realignment, by which previously reclaimed land is reconnected to the tidal influence by removal or breaching of defences and allowed to redevelop as saltmarsh. Vegetation tends to develop naturally and rapidly in these locations as they are often in areas with nearby saltmarsh which provides a source of seeds and propagules. The communities that develop on managed realignment sites however, often lack some of the species of nearby natural saltmarshes, such as sea lavender (*Limonium vulgare*), sea plantain (*Plantago maritima*) and sea pink/sea thrift (*Armeria maritima*) which are not as successful at spreading or establishing (Hudson *et al.*, 2021).

Creation of urban fringe saltmarsh is undertaken where hard defences are directly adjacent to intertidal habitat such as mudflat or shingle. In these instances, there is little horizontal space for saltmarsh, but engineering can make use of vertical space. These areas generally have little saltmarsh nearby and as such saltmarsh is unlikely to naturally develop, but the use of established plants from the outset can allow the habitat to persist.

Large-scale planting of saltmarsh in the UK is rare and generally considered unnecessary since sites naturally colonise with saltmarsh vegetation given a suitable supply of seeds and propagules from surrounding environments. One trial of such planting was undertaken at Tollesbury Marsh on the Blackwater Estuary in Essex in 1995. At this managed realignment site several treatments were trialled, including planting of seeds at high and low densities, propagation and planting of plug plants, and placement of small turfs. Following inundation, the survival rate for plugs and turfs was only 3% and no germination of planted seeds was observed (Garbutt *et al.*, 2006). It has been suggested that this trial was unsuccessful due to being too low in the tidal frame and subsequent trials by Mossman (2020) have shown that four years after planting, success rates can be over 60% when positioned at the appropriate elevation.

A list of example saltmarsh restoration projects currently proposed or being undertaken along the English coast are shown in Table 1. This is not an exhaustive list.

Table 1. Saltmarsh restoration projects

Project	Organisation(s)	Location	Restoration Method	Restoration Target
Restoring biodiversity around the Humber Estuary	Ørsted, Yorkshire Wildlife Trust, Lincolnshire Wildlife Trust	Humber Estuary	Planting	3ha
Lower Otter	Environment Agency	Exeter	Realignment	55ha
Arne Moors	Environment Agency	Poole Harbour	Realignment	150ha

Project	Organisation(s)	Location	Restoration Method	Restoration Target
Welwick and Skeffling	Environment Agency	Humber	Realignment	Up to 175ha (combined saltmarsh and mudflat)

## 2.2 Existing UK Saltmarsh Nursery Facilities

Facilities specialising in the growth of saltmarsh plants are relatively rare in the UK.

### 2.2.1 Commercial

Salix RW are a commercial plant supplier that supplies wetland plants to a variety of restoration, construction, and landscaping projects. Salix RW have an established plant nursery facility in Thetford, Norfolk based on a 1.5 acre site; this location focuses predominantly on freshwater wetland plants. Whilst saltmarsh plants do not require saltwater to grow, increased survival of transplants is observed when plants have been exposed to saltwater prior to planting out. Therefore, Salix RW have recently set up a large-scale estuarine nursery facility on a 42 acre site in Pendine, South Wales. This facility shares a site with a commercial ragworm farm and a seagrass nursery, making use of large outdoor artificial ponds where saltmarsh plants can be grown (Figure 1). Water is pumped to site from the Taf Estuary and once on site, the salinity is monitored and adjusted using freshwater to achieve the desired conditions. At present, seeds are still germinated in the Thetford facility and then transferred to Pendine for growth, but in the near future, the full saltmarsh process will be undertaken at the Pendine site, with a polytunnel used for germination.

The facility currently consists of 28 ponds/beds (1,000m<sup>2</sup> each) available for use. Each of these ponds has the capacity to support approximately 20,000 plants grown in coir rolls (Figure 1), or 100,000 plug plants. It is possible to grow plants from different locations at the facility. These can be kept in separate beds which can, in term of water flow, be isolated from the rest of the system. Cutting reproductive stems prevents cross-breeding by not allowing any of the plants to go to seed. Weekly checks are undertaken to remove any non-desirable or non-native species.

The wetland plant facility based in Thetford employs 18 full-time staff while the facility in Pendine currently employs 8 FTE across the saltmarsh, ragworm and seagrass ventures.

Salix RW estimate that setting up the facility in Pendine has taken investment of hundreds of thousands of pounds, possibly approaching £1 million, however this includes some commercial involvement with the ragworm and seagrass elements.



Figure 1. Photographs of the Salix RW saltmarsh nursery. Copyright Salix RW/D. Holland

Other plant suppliers are known to provide a limited number of saltmarsh plants and species, but there are no other known commercial nursery facilities in the UK focusing on saltmarsh plants.

## 2.2.2 Project and Academic

Other known saltmarsh nursery facilities in the UK are small project-specific or academic facilities. 'Green Shores' was a project run by St. Andrews University which aimed to create fringe saltmarsh in estuaries on the east coast of Scotland. As part of this project a coastal plant hub was built, consisting of a 14 x 4m semi-commercial polytunnel, in which several thousand plants could be grown to be later transplanted.

Saltmarsh research is also undertaken at Manchester Metropolitan University, where saltmarsh plants are grown in a large greenhouse. No specialist facilities are required to grow saltmarsh plants compared to terrestrial plant propagation. As discussed above, saltmarsh plants do benefit from exposure to saltwater prior to planting out, but this can be achieved using aquarium grade salt in freshwater, so does not require a seawater supply.

Costs were not available for these facilities, but investment predominantly related to purchase of a greenhouse/polytunnel along with land acquisition/rent. The facility at Manchester Metropolitan University is run by a single technician, while the Green Shores facility appears to have been run by one or two academic staff along with multiple volunteers, although this is unconfirmed.

## 2.3 Demand

Saltmarsh restoration projects in the UK do not regularly utilise nursery stock, as sites in suitable locations typically vegetate quickly once exposed to tidal influence. Evidence has shown that certain species do not readily establish within realignment or restored sites (Hudson *et al.*, 2021). There is potential that nursery grown plants could be utilised to encourage these particular species to develop within restored saltmarshes creating a community composition more similar to natural saltmarsh sites, or as adaptive management when saltmarsh restoration or recovery is not progressing as anticipated. Additionally, as policies such as Blue Carbon and BNG develop, there may be increased focus on the rapid development of specific saltmarsh communities rather than just general saltmarsh.

ReMeMaRe has a restoration target of 5,325ha by 2043. Recently the Wildfowl and Wetland Trust (WWT) have proposed that 22,000ha of saltmarsh be restored by 2050 to help achieve the UK Government's Net Zero commitment (WWT, 2022). Additionally, coastal squeeze may necessitate the creation of more urban fringe, engineered saltmarshes, in locations where hard defences are immediately adjacent to mudflat. These projects are likely to utilise nursery grown saltmarsh plants as the availability of local source is likely to be limited and the incorporation of established vegetation will be desired rather than waiting for natural development.

While the saltmarsh restoration manual (Hudson *et al.*, 2021) does not provide guidance on planting densities, a successful project on the River Medway, constructing a terraced saltmarsh, reported planting of

50,000 pre-grown saltmarsh plants over an area of 0.6ha<sup>3</sup> (equivalent to 83,333 plants per ha or 8.3 plants per m<sup>2</sup>) and American guidance suggests plant spacing of 0.45cm (Niedowski, 2000) (equivalent to approximately four plants per m<sup>2</sup>) may be appropriate for some species. Using an intermediate value of six plants per m<sup>2</sup> and acknowledging that the most successful planting densities will vary according to site conditions (Duggan-Edwards *et al.*, 2020), it can be estimated that to restore 1ha of saltmarsh would require 60,000 saltmarsh plants.

A facility such as that operated by Salix RW, could in theory produce up to 2.8 million plug plants in one year, enough for approximately 45ha of planted saltmarsh. Assuming that planting is undertaken for 25% of the WWT proposed 22,000ha of saltmarsh restoration, 330 million plants would be required over roughly 25 years, equivalent to 13.2 million per year. While it is unlikely that this level of planting will be undertaken, these numbers show that if planting were to be more widely used than currently, a five-fold increase in production may be needed. However, at the current rate of planting, it is unlikely that existing restoration targets will result in significantly increased demand for nursery stock and existing facilities, or small project-based facilities, will be able to supply demand.

## 2.4 Feasibility of Upscaling

### 2.4.1 Output volume

The set-up of a nursery facility for growing saltmarsh plants is relatively simple, consisting of predominantly a greenhouse/polytunnel as is used for normal plant propagation. There is little requirement for specialist equipment or resources.

Existing facilities, although based in Wales, are considered capable of dealing with demand to meet UK restoration targets and potential increases due to policy/strategy changes if projects continue to undertake limited planting. There is risk in relying on a single supplier or facility but the current demand for saltmarsh is such that, should the single supplier no longer be in operation, other facilities could be adapted to saltmarsh production, or demand could be met by small-scale project specific facilities.

However, if restoration methods change and large-scale planting becomes more widely used in the UK, a five-fold increase in production would be required to enable 25% of the target restoration area (22,000 ha) to be planted. Assuming a pond of 1,000m<sup>2</sup> can produce 100,000 plug plants, 13.2ha of ponds would be required to meet the annual target of 13.2 million plants.

### 2.4.2 Location

Location of a saltmarsh nursery facility is not considered to be of particular importance. While it is preferable to use plants from local stock for restoration, seeds can be collected from a donor marsh close to the restoration site and transported to the nursery facility to be cultivated before transport back to the site.

A single facility incorporating 13.2ha of ponds would be on the scale of industrial farming and is considered unfeasible. Sites of 2-3ha are considered more appropriate, requiring four to five such facilities to meet demand. If new facilities are to be established, it would be logical to site these at different locations around the coast. The Saltmarsh Restoration Potential map (Marine Management Organisation, 2019) indicates an abundance of potential habitat on the east coast of England, therefore this may be the most appropriate location for a nursery facility.

### 2.4.3 Costs

Information from Salix RW on the establishment of their Pendine facility, and exploration of costs, suggest an ROM estimate for initial investment in the range £262,500 - £612,500 for each 2-3ha facility (excluding planning, permitting and any associated infrastructure).

A large commercial facility could require up to 20 FTE but otherwise operating costs would be relatively low, related primarily to utilities, materials and maintenance. Information provided by the questionnaire responses

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<sup>3</sup> <https://www.aquaticengineering.co.uk/wp-content/uploads/2015/04/Salt-Marsh-Restoration.pdf>

suggest that capital set-up, staffing and operation/maintenance each account for 25 – 50% of annual costs with regulatory compliance and biosecurity accounting for the remaining 10 – 25%.

## **2.5 Saltmarsh Summary and Conclusions**

An analysis of the different options for upscaling saltmarsh nursery facilities is shown in Table 2.

At this time, it is not considered necessary to establish another saltmarsh nursery. To do so would require significant investment and may put existing suppliers at risk. However, if standard restoration practice changes such that demand increases significantly or existing suppliers exit the market, additional facilities could be created at strategic locations around the UK.

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**Table 2. Comparative analysis of options for upscaling saltmarsh nursery facilities**

Option	ROM Set-up cost	Operating Cost	FTEs	Annual Output	Annual Restoration Potential	Benefits	Disadvantages
<b>Commercial supplier</b>	n/a	n/a	n/a	Up to 2.8 million plants	46.7ha	<ul style="list-style-type: none"> <li>No initial investment</li> <li>Established facility, process and skill set</li> <li>Reliable output</li> <li>Local provenance can be provided upon request and with sufficient lead-in time</li> </ul>	<ul style="list-style-type: none"> <li>Long lead-in time for certain species</li> <li>Cost tied to commercial value</li> <li>No research potential</li> <li>No direct job creation</li> </ul>
<b>Small project-based saltmarsh nursery</b>	<£10,000	Low	2	<5,000 plants	<0.1ha	<ul style="list-style-type: none"> <li>Low cost</li> <li>Relatively quick to establish and initiate production</li> <li>Can be sited local to restoration site</li> <li>Job creation</li> <li>Opportunities for research</li> <li>Opportunities for education/outreach</li> </ul>	<ul style="list-style-type: none"> <li>Small-scale</li> <li>Likely to be temporary</li> </ul>

Option	ROM Set-up cost	Operating Cost	FTEs	Annual Output	Annual Restoration Potential	Benefits	Disadvantages
<b>Large-scale pond-based facility (2.5ha)</b>	£260,500 - £612,500	Low	20	1 million plants	16.7ha	<ul style="list-style-type: none"> <li>Job creation</li> <li>Established process</li> <li>Research opportunities</li> <li>Volunteering opportunities</li> <li>Education/outreach opportunities</li> <li>Local provenance can be maintained</li> </ul>	<ul style="list-style-type: none"> <li>Significant initial investment</li> <li>Large physical footprint</li> </ul>

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### 3. Seagrass

#### 3.1 Seagrass Restoration Overview

The Seagrass Restoration Handbook (Gamble *et al.* 2021) gives a detailed account of the different processes and methods of seagrass restoration. A summary of this information is provided below as context for the requirements of nursery facilities.

Seagrass restoration projects have gained significant momentum in the past decade or two. In the UK seagrass restoration focuses on two species, *Zostera marina* or common eelgrass which mainly occurs subtidally to depths of up to 5m and *Zostera noltei* or dwarf eelgrass which is the smaller of the two species and is predominantly intertidal. *Zostera* species can produce either sexually through the development of flowering shoots, or vegetatively by sending out rhizomes. The lifecycle of seagrass is shown in Figure 2.

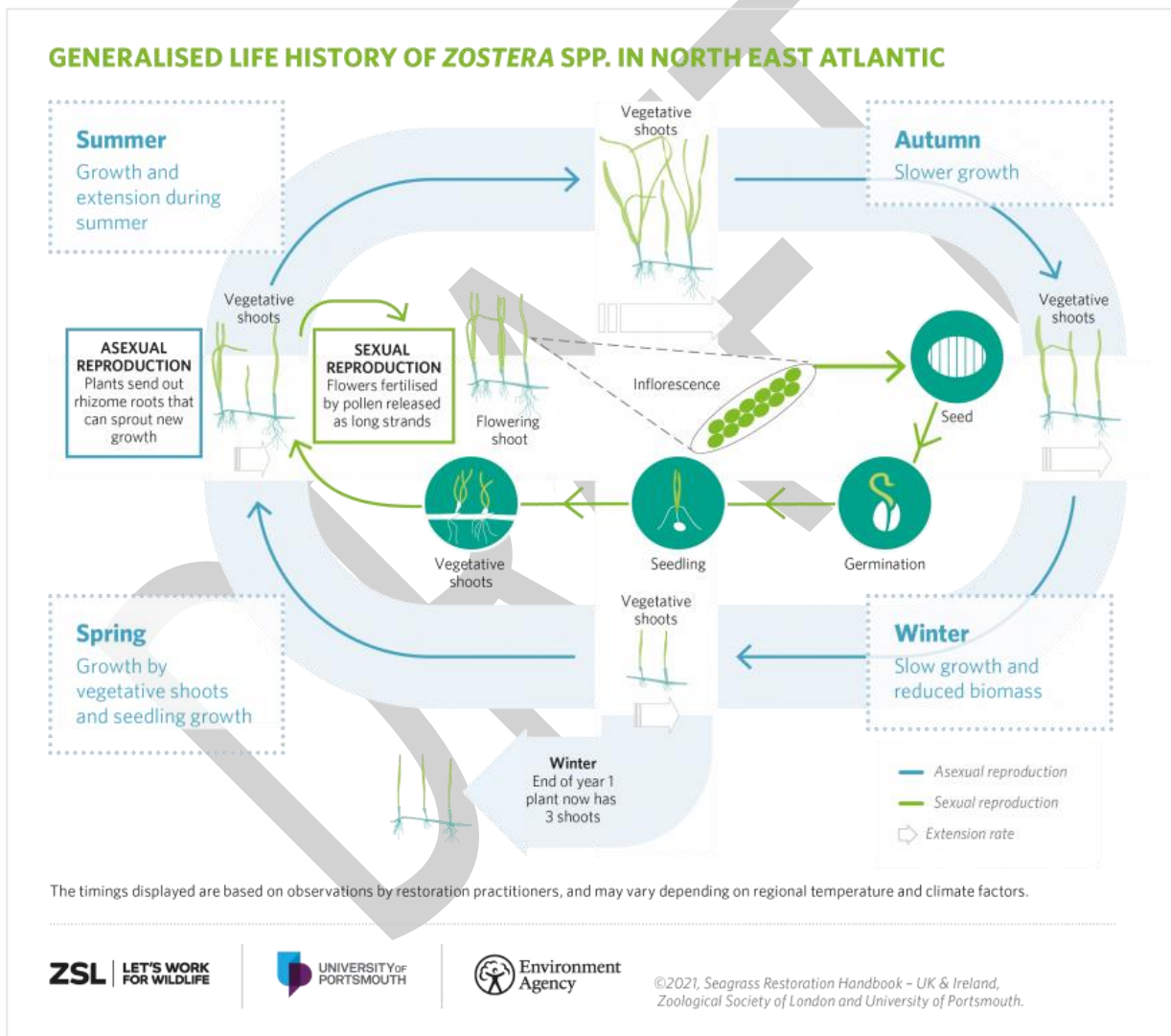


Figure 2. Seagrass lifecycle (Gamble *et al.* 2021).

Most projects rely on collection of seeds from existing seagrass meadows between mid-summer and early autumn when the flowering shoots (spadices) can be collected causing no damage to the plant. The Buoy Deployed Seeding (BuDS) method of restoration involves placing these shoots into mesh bags attached to buoys and allowing the seeds to naturally drop out. However, in the majority of cases the shoots are brought back to a processing facility where they are stored in large tanks of aerated or circulating seawater while the shoots ripen and release the seeds that are negatively buoyant and sink the base of the tank. This process can

take up to two months. The seeds can be used straight away for seed-based restoration or further cleaned of any remaining detritus either manually or via upwellers and stored.

Studies have shown that seed-based methods often result in high seed losses (>99%) and poor establishment, thought to be due to predation and mobilisation of sediments caused by high wave energy during winter (Govers *et al.*, 2022; Cronau *et al.*, 2023). Plant-based restoration, especially at the trial scale, has traditionally relied on direct transplants from donor beds, but this has the potential to cause damage to donor beds and result in low genetic diversity (Williams, 2001).

The most commonly used restoration method in the UK involves placing high quantities of seeds (known densities of between 15-100 have been used) into small biodegradable hessian bags, filled with sediment and seagrass material. These seed bags are then either dropped to the seabed, buried under the surface of the seabed or fixed along a length of rope that is weighted on the seabed. In doing this the seeds are provided some protection from predators and environmental pressures such as large tidal ranges or storm surges. Success rates have been shown to be as high as 94% for seed bag germination, with a 3.6% seed success rate within each bag (Unsworth *et al.* 2019). This method is suitable for small projects as no seed storage or growing facilities are required, however the process of filling and deploying bags is labour intensive.

Current UK projects also make use of plant-based restoration involving the germination and growth of seagrass seeds on biodegradable mats before fixing the entire mat to the seabed. This method has the benefit of allowing the seedlings to germinate and grow in a sheltered nursery environment before planting out. By transplanting the entire mat, the existing microbiome that the seedlings have developed is transplanted with them and has shown promising success (M Parry 2023, personal communication, 3 March). The current method used by the Ocean Conservation Trust is to plant 100 seeds per mat and once germinated, the mats are transplanted at 3m intervals.

Seagrass restoration throughout the UK and Europe is still predominantly in the form of trials and experiments. Progress has been reported in the use of Dispenser Injection Seeding (DIS) using sealant guns to inject a mixture of seeds and sediment into the seabed (Gräfnings *et al.*, 2022; Govers *et al.*, 2022). This method has reported seed recruitment rates of 11.4% (Gräfnings *et al.*, 2022).

A summary of known seagrass restoration projects currently being undertaken along the English coast are shown in Table 3. This is not an exhaustive list.

**Table 3. Current seagrass restoration projects in England**

Project	Organisation(s)	Location	Species	Restoration Method	Restoration Target
<b>Blue Meadows</b>	Ocean Conservation Trust	South coast	<i>Z. marina</i>	Seedling mats	n/a
<b>ReMEDIES</b>	Natural England, Ocean Conservation Trust, Marine Conservation Society, RYA, Plymouth City Council/Tamar Estuaries Consultative Forum	Solent Maritime SAC  Plymouth Sound NMP	<i>Z. marina</i>	Currently seed bags but exploring other methods	4ha in each location
<b>Seagrass Ocean Rescue</b>	Project Seagrass, Swansea University, WWF	Isle of Wight	<i>Z. marina</i>	Seed bags	2ha

Project	Organisation(s)	Location	Species	Restoration Method	Restoration Target
<b>Solent Seagrass Restoration Project</b>	Hampshire & Isle of Wight Wildlife Trust, Boksalis Westminster, University of Portsmouth	Solent	<i>Z. marina</i> and <i>Z. noltii</i>	Seed bags	n/a
<b>Seeding Change Together</b>	Cornwall Wildlife Trust, Seasalt Cornwall	Fal Estuary	<i>Z. noltii</i>	Seed bags	n/a
<b>Restoring biodiversity around the Humber Estuary</b>	Ørsted, Yorkshire Wildlife Trust, Lincolnshire Wildlife Trust	Humber Estuary	<i>Z. noltii</i>	Seed bags	4ha
<b>Humber Seagrass Restoration</b>	Ørsted, Yorkshire Wildlife Trust	Humber Estuary	<i>Z. noltii</i>	Seed bags Seagrass nursery	30ha (74 acres) over 7 years
<b>Seavive</b>	Bournemouth University, Gulf Agency Company, Falmouth Harbour, Our Only World	Falmouth	n/a	Prototype seed processing pod, Seed bags	n/a

## 3.2 Existing UK Seagrass Nursery Facilities

Seagrass nurseries in the UK are a relatively new development, with most only set up within the last 2-3 years and still trialling the best methods for seagrass growth. Several projects undertake small-scale seed processing. These facilities are not considered here but are included with the relevant nursery facility where applicable. Anecdotal evidence suggests that the Yorkshire Wildlife Trust either have, or are planning a seagrass nursery facility, however no information could be obtained during this study and as such it is not included here.

### 3.2.1 Swansea University – Seed Processing Facility

The seed processing facility operated by Swansea University is the base for seagrass restoration upscaling research for the Seagrass Ocean Rescue project and contains around 20 IBC (Intermediate Bulk Container) tanks used for different treatments of seagrass seed processing. The current facility does not have a direct seawater connection and is reliant on two large storage tanks. Regular water changes, drum filters and aerators are used to maintain water quality. The system can be configured in several different ways depending on the trial being undertaken and can include a fully connected system or a number of smaller closed systems. Current trials are exploring the use of a motorised fluid agitator to separate seed from decomposing seagrass material and early results suggest that this can reduce the effort and time required (S Rees 2023, personal communication, 15 March).

Depending on the method used for collection of the spadices, it is estimated that at full capacity the facility could process up to 5 million seeds per year. Manual seed collection is labour intensive, with 25 staff and volunteers taking 10-12 days to gather 200,000 – 400,000 seeds. Early trials of a seagrass mower suggest it

could harvest over 3 million seeds in one day but collects up to 10 times as much extra plant material, requiring either additional manual processing or limiting the processing efficiency per tank (S Rees 2023, personal communication, 15 March).

The facility employs 3 FTEs and it is estimated that set-up costs were approximately £30,000 - £50,000, although a number of the IBC tanks were donated.

### 3.2.2 Ocean Conservation Trust - Blue Meadows Nursery

Under the Blue Meadows project, Ocean Conservation Trust set up a seagrass (*Zostrea marina*) nursery facility in Torbay, Devon in 2022. This facility consists of a large (400m<sup>2</sup>) polytunnel containing 30cm deep ponds constructed using sleepers and pond liners (Figure 3). Water is extracted directly from the Dart Estuary at no more than 20m<sup>3</sup> per day and goes through sand filters prior to entering the system. The water is not subject to heating or chilling or any form of UV or chemical treatment.

Seed processing can be undertaken on-site using the ponds. Seeds are currently stored in fridges with water changes every 2-3 days, however, a specific seed storage unit has been ordered.

The facility operates during the summer only. Trays containing hessian mats are placed in the ponds and 100 seagrass seeds are germinated in each mat and grown on for approximately 12 weeks before the mats are then planted out into restoration sites. Fish blood bone fertiliser is added to the system to aid growth of the seedlings. In one year this facility can produce 600 seedling mats, which when planted at 3m intervals, covers 1.5ha of a restoration site.

Approximate costs associated with setting up this facility include £30,000 - £35,000 for the polytunnel and £14,000 annual rent. The optimal staffing level for the facility is 2.5 FTEs. Volunteers have been used in the facility but are not essential.



Figure 3. Photographs of Blue Meadows seagrass nursery. *Copyright Ocean Conservation Trust*

### 3.2.3 Ocean Conservation Trust – National Marine Aquarium

As part of the ReMEDIES project, an indoor seagrass (*Zostera marina*) nursery (seagrass laboratory or lab) has been set up within the National Marine Aquarium in Plymouth, run by the Ocean Conservation Trust. As this facility is within the aquarium and is visible to the public there is a focus placed on presentation that is not necessarily considered in other facilities.

Water for the whole aquarium is abstracted via sump from Sutton Harbour and passes through multiple filtration systems (physical, chemical and biological). The seagrass lab receives this clean filtered water but has its own closed recirculatory system, separate from the rest of the aquarium, that contains no more than 10,000 litres. Salinity does vary naturally but it is supplemented with aquarium grade salt to stay at 32ppt. Freshwater can also be added within the lab as necessary. The seawater supply is generally 15-16°C although the facility has a chiller that can take the water down to 7°C. Technical checks are undertaken daily, with regular water quality checks and a weekly 50% water change.

The clarity of the water in the lab is good, but epiphytic (filamentous) algae is a problem. Biological control in the form of barley extract is used, which releases hydrogen peroxide when it degrades. This kills simple algae, but the more complex the algae the less effective the treatment is.

Within the lab, 1m<sup>2</sup> trays are used to grow seedlings in hessian mats, which can then be transplanted to restoration sites. The lab can currently accommodate 37 trays across two tiers. The top tier of 20 trays is lit using specialist aquarium lighting with an output of around 150 PAR at 10m, while the bottom tier of 17 trays is lit using horticultural LED lighting with an output of around 150-220 PAR. No analysis has been undertaken but there does not appear to be a significant difference between the two. The lighting operates for 18 hours a day and is adjusted throughout the day to replicate natural daylight patterns.

An attempt was made to process seeds on-site in an aquarium tank, however as the aquarium is open to the public, the presence of significant amounts of decomposing plant material was undesirable. Therefore, seed processing was moved to the nursery facility in Devon.

Due to the controlled nature of the lab conditions, this facility can operate year-round producing 100 seedling mats per run (approximately 12 weeks). Over 2 years enough mats have been grown to cover approximately 1.6ha of a restoration site.

Costs for the seagrass lab are not available as costs are borne by the wider aquarium facility. However, one element of the system for which approximate costs were provided was the lighting. The specialist aquarium lighting utilised for the top tier has an approximate cost of £7,000. This lighting was originally anticipated to be sufficient for the two tiers of trays but initial trials indicated that the level of light produced was insufficient for seagrass growth and so the lighting for both tiers was combined onto just the top tier. Additional horticultural lighting was acquired for the bottom tier which was significantly less expensive, and being LED, is less expensive to run.

The seagrass lab is run by a single technician, but with assistance from other aquarium staff when required.

### 3.2.4 Project Seagrass/Salix RW – Pendine

Project Seagrass, in partnership with Salix RW and with funding from the Aviva Community Fund set up a seagrass (*Zostera marina*) nursery facility in Pendine, South Wales in 2021/2022. The facility is located on the same site as the Salix RW saltmarsh nursery facility described above. The seagrass nursery currently occupies a polytunnel (26ft x 54ft) which contains six lined and insulated ponds each 2.3m x 2.3m x 0.5m (Figure 4). Water abstracted from the Taf Estuary is held in the lagoon on site and then fed by sump through a microbead filter and 10-bulb UV filter into the seagrass facility. The use of the UV filter is primarily to sterilise any ragworm eggs that are retained in the system from the ragworm farm. The seagrass facility operates a closed recirculatory system which utilises a combination heater/chiller to simulate the monthly average water temperature at the seagrass donor site. Salinity is not altered within the system and will fluctuate with natural conditions.

Although not yet operational, several outdoor ponds on the sites are currently being repurposed for seagrass growth. These ponds will not be subject to any form of physiochemical control (i.e. temperature, salinity or filtration).

The Pendine facility has an on-site seed storage facility that consists of a refrigerated shipping container. Within the container, seeds from multiple locations are stored in separate closed recirculatory systems using artificial seawater (50ppt) to avoid issues of biosecurity and cooled to 2°C to avoid germination. Currently only seeds from the Welsh donor site are germinated and grown in the facility. Seeds from other locations (currently Isle of Wight) are stored only.

The initial aim of the seagrass nursery is to trial different methods of seagrass growth, with the intention of growing reproductive plants from which seeds can be collected to reduce the effort required to collect seeds from wild beds. With this aim in mind the facility operates year-round but as it is only entering the second year of operation, no indication of output is available. The first year of trials has yielded a success rate of approximately 6%, nine months after planting, with 400 plants surviving after an outbreak of seagrass wasting disease.

The seagrass nursery currently employs two FTE, but volunteers provide a vital contribution to the set-up and maintenance of the facility.

Specific costs were not available for the set-up of the site and it is unclear how much of this is covered by the costs discussed for the Salix facility described in Section 2, however costs would primarily be related to purchase of the polytunnel, filters, pond construction materials, sump, refrigerated container for seed storage and staffing.



Figure 4. Photographs of Project Seagrass/Salix RW seagrass nursery. Copyright Project Seagrass/E. Yates

### 3.2.5 Seawilding – Loch Craignish

Seawilding is a habitat restoration project based at Loch Craignish on the west coast of Scotland. In collaboration with Project Seagrass, the project has set up its own seagrass (*Zostera marina*) seed processing and nursery facility.

The seed processing facility consists of four 1,000 litre plastic IBC tanks, two for storage of plant material and two as header tanks for water storage. A portable immersion pump is used to fill header tanks from the sea and also to assist with the 50% water change every 2-3 days. The plant material remains in these tanks for up to 2 months before seeds are gathered using nets and sieves to separate seeds from rotted plant material. Seeds are stored short-term in mesh bags suspended in the tanks prior to planting out.

A small-scale trial nursery facility was set up in late 2022/early 2023 with the aim of improving seed germination rates and moving towards transplant of seedlings rather than use of seed bags. The set-up consists of two plastic IBC header tanks and four tanks for seagrass growth trials (Figure 5). Currently the facility is set up outdoors on the Craignish commercial plant nursery site and uses artificial seawater.



Figure 5. Photographs of the Seawilding seagrass nursery. *Copyright Seawilding/P. Price*

### 3.3 International Examples of Seagrass Nursery Facilities

#### 3.3.1 Florida Atlantic University – Florida, USA<sup>4,5</sup>

To help with recovery efforts of seagrass in Florida, a staple of the manatee population, the Florida Atlantic University is experimenting with growing seagrass (shoal-grass (*Halodule* sp.)) in six large outdoor tanks from seagrass collected from the Indian River Lagoon, and then transplanting back to the Indian River Lagoon to restore lost seagrass beds. The seagrass is maintained in 'ready mode' to be able to supply established seagrass to projects.

Research is exploring the genetic diversity of the Indian River Lagoon seagrasses and how that diversity might be best used to support seagrass restoration in the lagoon, including selection of strains that have favourable traits such as rapid growth and broader environmental tolerance.

In 2021 the University received a grant from Florida Power & Light Company and funding from the Florida Fish and Wildlife Conservation Commission to extend the existing seagrass nursery and fund operation costs for at least three years.

#### 3.3.2 Florida Fish and Wildlife Conservation Commission – Florida, USA<sup>6</sup>

The Florida Fish and Wildlife Conservation Commission (FWC) is experimenting with a tissue-culture technique, micropropagation, to try and develop a sustainable stock of seagrass for seagrass restoration projects without causing damage to existing seagrass beds. This method has the potential to produce more plants in less time than traditional methods.

Micropropagation involves collecting terminal buds from mature plants and placing them in test tubes with specific nutrient mediums, so there is no reliance on seeds. The media used to grow buds is an area of research the FWC is currently investigating. Once able to maintain a rapidly multiplying plant stock in the laboratory (lab), they can be used as a source of additional micropropagation or subculturing (dividing plants into smaller segments and growing mature plants from these pieces). Clones can be screened for different attributes and used for specific applications, or genetic variability can be assured by mixing different clonal strains in restoration projects. Currently FWC grow the tassel weed Widgeon-grass (*Ruppia maritima*) in the lab using this method and are in the process of developing this technique for seagrass species such as shoal-

<sup>4</sup> <https://www.fau.edu/hboi/discover-fau-harbor-branch/virtual-resources/virtual-tours/>

<sup>5</sup> <https://www.birminghamtimes.com/2022/02/seagrass-nursery-to-serve-starving-manatees-in-florida/>

<sup>6</sup> <https://myfwc.com/research/habitat/seagrasses/projects/active/restoration/>

grass (*Halodule* sp.), manatee-grass (*Syringodium filiforme*) and turtle-grass (*Thalassia testudinum*), which are increasingly difficult.

In addition to experimenting with micropropagation, the FWC are developing a new method of planting involving a boat with a planting wheel, that will reduce the damage to plants and effort required for manual planting.

### 3.4 Demand

Demand will depend on the restoration methods employed for future projects. If projects continue to use predominantly seeds as the main stock, it is likely that demand can be met by through the establishment of project specific facilities, as these are relatively simple and deliver high yields. If restoration efforts move towards the use of established plants, due to greater survivability, there would be a requirement for significantly upscaling facilities. Existing nursery facilities are small-scale and typically research focused. In order to produce seagrass plants in significant numbers, it will be necessary to create facilities substantially larger than existing.

In order to estimate demand, the following requirements for each restoration have been calculated using information provided by study participants and from the literature:

- Seeds (seed bags): 500,000 seeds per ha (1 seed bag per m<sup>2</sup>, 10,000 seed bags per ha, 50 seeds per bag)
- Seeds (DIS): 5,000,000 seeds per ha (500 seeds per 1m<sup>2</sup> (Gräfnings *et al.*, 2022))
- Seedling mats: 40,000 seeds per ha (400 seedling mats)
- Plug plants: 5,000 plants per ha (5 plants per m<sup>2</sup>)<sup>7</sup>

In order to meet ReMeMaRe's conservative seagrass restoration targets of 550ha using current methods and planting densities the following will be required:

- 275 million seeds (5.5 million seed bags)
- 2.75 billion seeds for DIS
- 22 million seeds (220,000 seedling mats)
- 45.8 million seeds (2.75 million plants)

### 3.5 Feasibility of Upscaling

#### 3.5.1 Output Volume

The Global Seagrass Nursery Network are currently developing a seagrass nursery handbook which may in time provide guidance on the best set-up for large-scale seagrass facilities, however this handbook is not anticipated to be available in the immediate future.

Current methods of restoration are labour intensive and are unlikely to produce the desired large-scale restoration over the target timeframe. Many institutions and projects are assessing methods of upscaling restoration, for example through mechanised seed planting or micropropagation, therefore it is difficult to determine the most suitable facility required for upscaling restoration. The feasibility of upscaling presented here is based on currently available information.

ReMeMaRe restoration targets are set to be achieved by 2043, however a period of 15 years has been used to calculate required output to make allowance for time taken to establish any new facility. Table 4 presents the values used to establish approximate facility requirements.

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<sup>7</sup> OSPAR describe *Zostera* beds as having cover of >5%.

Table 4. Values used to determine facility requirements

Production Method	2043 Target	Annual Target	Approximate Annual Unit Output	Production Requirement
Seed processing	275 million seeds (seed bags)	18.3 million seeds	200,000 per IBC tank	92 tanks
	2.75 billion seeds (DIS)	>180 million seeds	200,000 per IBC tank	920 tanks
Seedling mat (lab-based)	220,000 mats	14,700 mats	9 per m <sup>2</sup> growing space	1,850m <sup>2</sup>
Seedling mat (polytunnel pond-based)	222,000 mats	14,7000 mats	3 per m <sup>2</sup> growing space	4,900m <sup>2</sup>
Individual plants (polytunnel pond-based)	2.75 million	183,000 mats	15 per m <sup>2</sup>	12,200m <sup>2</sup>

### Seed Processing

The seed processing facility operated by Swansea University, if operating at capacity has an estimated output of five million seeds per year depending on collection method. In order to meet a target of 275 million seeds in 15 years, processing would have to quadruple. To process the 2.75 billion seeds required for DIS, over 36 similar facilities would be required.

### Seedling Mat Production

To meet the anticipated demand utilising seed mats produced in small indoor facilities with artificial lighting (hereafter 'lab or lab-based facilities') similar to that at the National Marine Aquarium, which produces 300 mats per year, a 50-fold increase in production would be required.

The approach taken at the Blue Meadows nursery, through the use of a polytunnel, can produce twice as many seedling mats over a single summer but order to meet the demand of 220,000 seedling mats over 15 years, would still require a facility more than 23 times the size of the existing facility. Based on the Blue Meadows set up, provision of 4,900m<sup>2</sup> of growing space would require around 9,800m<sup>2</sup> of polytunnel space.

### Individual Plant Production

The small facility operated by Project Seagrass reported survival of 400 plants from their initial trials. It is acknowledged that this would likely be higher when focusing solely on production rather than trials, when space could be used more effectively, and has therefore been increased by approximately 25%. Even so, more than 360 similar small-scale facilities would be required to meet the demand for 183,000 plants annually.

The use of vegetative propagation of seagrass is not widely used as a restoration method at this time, and therefore it is difficult to consider such a facility in terms of potential output and contribution to upscaling restoration effort.

### **Combined Facility**

Different locations will benefit from different restoration methods and it has been suggested that subtidal conditions with high wave exposure and lugworm (*Arenicola* sp.) densities will be most successful when restored with transplants, whereas relatively calm, or intertidal areas can benefit from the scaling potential of seed based restoration (Croneau *et al.* 2023). Therefore, upscaling seagrass restoration is likely to require a combination of seed processing and seedling propagation facilities.

A combined facility processing 10 million seeds per year could allow 0.5 million seeds for production of approximately 5,000 seed mats (up to 12.5ha), while still producing 9.5 million seeds for seed bags (190,000 seed bag, up to 19ha) or DIS (up to 2ha). An example configuration for such a facility could be:

- a large building (150m<sup>2</sup>) for seed processing, incorporating up to 50 IBC tanks (or a smaller number of larger tanks) with a recirculating system. The building would also include an area for seed washing, bagging, etc. and office/welfare facilities;
- an insulated container for seed storage with a closed recirculating system using chilled artificial seawater;
- a large building (150m<sup>2</sup>) for year-round indoor propagation of seedlings (up to 200m<sup>2</sup> growing space (1,500 seedling mats)) with lighting and recirculating, heated/chilled and filtered water;
- 2,400m<sup>2</sup> polytunnels containing 1,200m<sup>2</sup> ponds (up to 3,600 seedling mats) using recirculating filtered water; and
- a direct seawater abstraction would be required in addition to substantial water storage capacity in the form of an outdoor lagoon or multiple large storage tanks.

The manual collection of 10 million seeds per year is unachievable. The use of mechanised seed collection will potentially be required. While evidence suggests this does not result in damage to the donor bed (S Rees 2023, personal communication, 15 March), it will result in significant amounts of excess plant material at the processing stage. Due to the seasonality of seagrass growth in the ponds, it would be possible to use the polytunnel ponds to aid with processing of the large amount of excess plant material.

### **3.5.2 Location**

A significant proportion of seagrass restoration projects are focused on the south coast of England, and existing seagrass nurseries are based in Plymouth and Torbay, in addition to the nursery in Pendine South Wales. The Seagrass Restoration Potential map (Environment Agency, 2021) indicates that, beyond the south coast, areas of potential seagrass habitat are predominantly around the south east and north west English coast, with fewer potential areas in the north east.

Restoration projects should aim to maintain local genetics, assuming there is sufficient local genetic diversity, as there is potential for populations to be adapted to certain conditions such wave exposure, temperature and light availability (Pazzaglia, *et al.*, 2021). Seed processing and storage can be undertaken relatively easily in any location as these have lower biosecurity concerns for seed processing and involve relatively small quantities of water for seed storage making artificial or sterilised seawater a viable option. However, it is unrealistic to move large quantities of seagrass material significant distances to be processed. Large scale propagation of seagrass seedlings is likely to involve more open systems and therefore locations close to the restoration site are preferable to limit the biosecurity concerns. As such it would be recommended that any establishment of facilities be based in the south east and north west to enable suitable stock to be supplied to restoration projects in these regions.

### **3.5.3 Cost**

As there is currently no clear primary method for seagrass restoration, a comparison of costs for different types of facility are provided. Although costs are presented separated, it is likely that a single facility will incorporate several elements (i.e. seed processing, seed storage and seedling growth). A breakdown of approximate costs is presented in Appendix B. Costs do not include planning, permitting, or construction of associated infrastructure (i.e. access roads or utilities connections) as these would be determined by the site location. The scenarios presented assume full demand is to be met by a single facility, and do not take into account contribution from other sources.

For a large-scale isolated seed processing and storage facility, capable of processing up to 20 million seeds per year an ROM estimate for establishment costs in the range of £189,675 - £442,575 was found. Such a facility would employ approximately 10 FTEs, typically on a seasonal basis. Otherwise, operating costs are

predicted to be low to moderate, predominantly associated with utilities and maintenance. Questionnaire responses regarding small scale processing facilities indicate that staffing accounts for 75 – 90% of annual costs and operation/maintenance accounts for less than 10%. While this ratio may change slightly due to the scale of the facility, it gives an indication of where the main costs lie for seed processing.

For a lab-based seedling nursery, capable of producing 15,000 seedling mats per year, we found an ROM estimate for set-up costs in the range of £881,250 - £2.06 million. Such a facility would employ approximately 20-30 FTEs. Operating costs are predicted to be relatively high, primarily related to materials and utilities, with a higher energy demand due to the requirement for artificial lighting. No information is available for this specific type of facility, however a similar aquatic laboratory indicated that the main costs were staffing (25 - 50%) and operation/maintenance (10 – 25%).

For a large-scale polytunnel-based nursery, capable of producing 15,000 seedling mats per year, we found an ROM estimate for set-up costs in the range of £402,675 – £939,575. Such a facility would employ 20-30 FTEs, mostly on a seasonal basis. Otherwise, operating costs would be low to moderate depending on the level of environmental control, and predominantly associated with utilities and maintenance.

For a large-scale polytunnel-based nursery, capable of producing 183,000 individual plants per year, an ROM estimate for set-up costs in the range of £927,300 – £2.16 million was found. Based on scaling up of existing small poly-tunnel based nurseries producing individual seagrass plants, such a facility would employ over 100 FTEs, however, based on similar facilities producing saltmarsh or seagrass seedling mats, a more realistic number of 20-30 FTEs is predicted. Otherwise, operating costs would be low to moderate depending on the level of environmental control, and predominantly associated with utilities and maintenance.

Outdoor ponds for growth of seagrass are not yet utilised in the UK, however if trials show this to be a viable method, this may become an appropriate method for large-scale production, therefore approximate costs have been provided. A large-scale pond-based seagrass nursery, capable of producing 15,000 seedling mats per year would require up to 5,000m<sup>2</sup> of pond area and an ROM estimate for set-up costs in the range of £153,750 – £358,750 was found. Such a facility would employ approximately 10 FTEs. Otherwise, operating costs would be relatively low, predominantly associated with utilities and maintenance.

None of these facilities, in isolation, represents a feasible approach to upscaling seagrass restoration. A combined facility, as presented in Section 3.5.1 would require a site of around 0.5ha and would have an ROM estimated set-up cost in the range of £323,700 – £755,300. This type of site would employ around 10-15 FTEs and would have moderate operating costs. The facility as presented would be below target output, however different adaptations to the set up or a second facility would meet demand.

### **3.6 Seagrass Summary and Conclusions**

A comparative analysis of the different options for upscaling seagrass nursery facilities is shown in Table 5.

A seed processing facility could meet the required demand for seed-based restoration using seed bags, but would not include any ability to upscale seedling production. Both the lab-based and polytunnel-based systems would require significant investment. The primary benefit of the polytunnel or pond-based nursery is the low energy requirement, with no lighting and little requirement for heating or chilling the water. By comparison a lab-based nursery would require artificial lighting for several hours a day and to enable year-round production it is likely that the water will require heating/chilling.

While it would be feasible to meet demand with facilities focused on one restoration/production method, the suitability of different restoration approaches in different conditions, and the on-going research in multiple areas, suggests that combined facilities are the most appropriate solution to upscaling production. This reduces the risk associated with investing in a single method. Presented above is an example facility that could incorporate multiple methods on one large site, however it would likely be preferable to split this into two (or more) smaller facilities that could be established in different regions of the country.

Investment in existing facilities was not assessed as a separate option for seagrass, as the limited scale of the facilities means that many of the costs associated with establishment of new sites would still be encountered. There would however be potential benefits in terms of location and infrastructure.

**Table 5. Comparative analysis of potential options for upscaling seagrass production**

Option	ROM Set-up Cost	Operating Cost	FTEs	Annual Output	Annual Restoration Potential	Benefits	Disadvantages
<b>Large-scale seed processing &amp; storage</b>	£189,675 - £442,575	Low/Moderate	10	20 million seeds	4 - 40ha	<p>Job creation</p> <p>Potential opportunity for circular economy relating to use of saltmarsh material as compost/fertiliser</p> <p>Limited technology required</p> <p>Established process but also opportunity for research into improved methods</p> <p>Volunteering opportunities</p>	<p>Operation is seasonal</p> <p>Unrealistic to move large quantities of seagrass material long distances for processing</p>
<b>Lab-based seedling mats</b>	£881,250 - £2.06 million	High	20-30	1.5 million seeds (15,000 mats)	37.5ha	<p>Job creation</p> <p>Opportunities for research</p> <p>Year-round production</p> <p>Reliable output</p>	<p>Significant financial investment</p> <p>Space limitations</p> <p>Developing research into growing methods may result in the</p>

Option	ROM Set-up Cost	Operating Cost	FTEs	Annual Output	Annual Restoration Potential	Benefits	Disadvantages
							lab becoming less favourable
<b>Polytunnel based seedling mats</b>	£402,675 – £939,575	Low/Moderate	20-30	1.5 million seeds (15,000 mats)	37.5ha	Job creation Opportunities for research Volunteering opportunities	Significant financial investment Large physical footprint Current practice is seasonal
<b>Polytunnel based plug plants<sup>8</sup></b>	£927,300 – £2.16 million	Low/Moderate	>100	3.05 million seeds (183,000 plants)	36.6ha	Job creation Opportunities for research Volunteering opportunities Significant potential for improved output	Significant financial investment Large physical footprint
<b>Outdoor pond seagrass growth</b>	£153,750 – £358,750	Low	10	1.5 million seeds (15,000 mats)	37.5ha	Relatively low investment Job creation	Higher biosecurity risk Not an established method for

<sup>8</sup> Low confidence in estimate of output. Potential significant underestimate of output resulting in gross overestimate of

Option	ROM Set-up Cost	Operating Cost	FTEs	Annual Output	Annual Restoration Potential	Benefits	Disadvantages
						Seagrass can be stored for long periods with relatively limited input becoming more established prior to translocation	seagrass growth in the UK
<b>Combined seagrass facility</b>	£323,700 – £755,300	Moderate	10-15	10 million seeds (5,000 seedling mats and 190,000 seed bags)	14.5ha – 33.5ha	<p>Job creation</p> <p>Spread of risk between different methods</p> <p>Can supply multiple types of restoration</p> <p>Research opportunities</p> <p>Volunteering and educational/outreach opportunities</p>	<p>Large physical footprint</p> <p>Relatively large initial investment</p> <p>Multiple sites may be required to achieve targets (could be scaled up or down to account for this)</p>

## 4. Oyster

### 4.1 Oyster Restoration Overview

The European flat oyster (*Ostrea edulis*) is the only oyster native to the UK. Native oyster restoration differs from saltmarsh or seagrass restoration in that there is a commercial value for native oysters, therefore a significant proportion of existing restoration efforts are being undertaken with the aim of restoring a sustainable commercial fishery. Following the native oyster population collapse in the mid-1900s, commercial oyster fishermen turned to farming the non-native Pacific oyster (*Crassostrea gigas*, also known as *Magallana gigas*). However, with increased awareness to the environmental importance of the native oyster, significant efforts are being made to re-introduce the species and restore historic beds.

The European Native Oyster Habitat Restoration Handbook (Preston *et al.* 2020) gives a detailed account of the processes and methods of native oyster restoration. A high-level summary of that information is provided here for context in relation to hatchery and aquaculture facilities.

The lifecycle of the native oyster is illustrated in Figure 6. Native oysters are protandrous alternating hermaphrodites, starting life as males producing sperm and then switching to egg producing females, back to males and so on. Gamete maturation begins in late spring in the UK and is temperature dependent. After sperm is released by the males, it is inhaled by the females who fertilise and brood the eggs internally for 7-10 days before releasing free-swimming larvae. The larval phase lasts for approximately two weeks before the larvae begin to seek out suitable settlement substrates. Within 48hrs of settling, the spat is permanently attached and begins filter feeding.

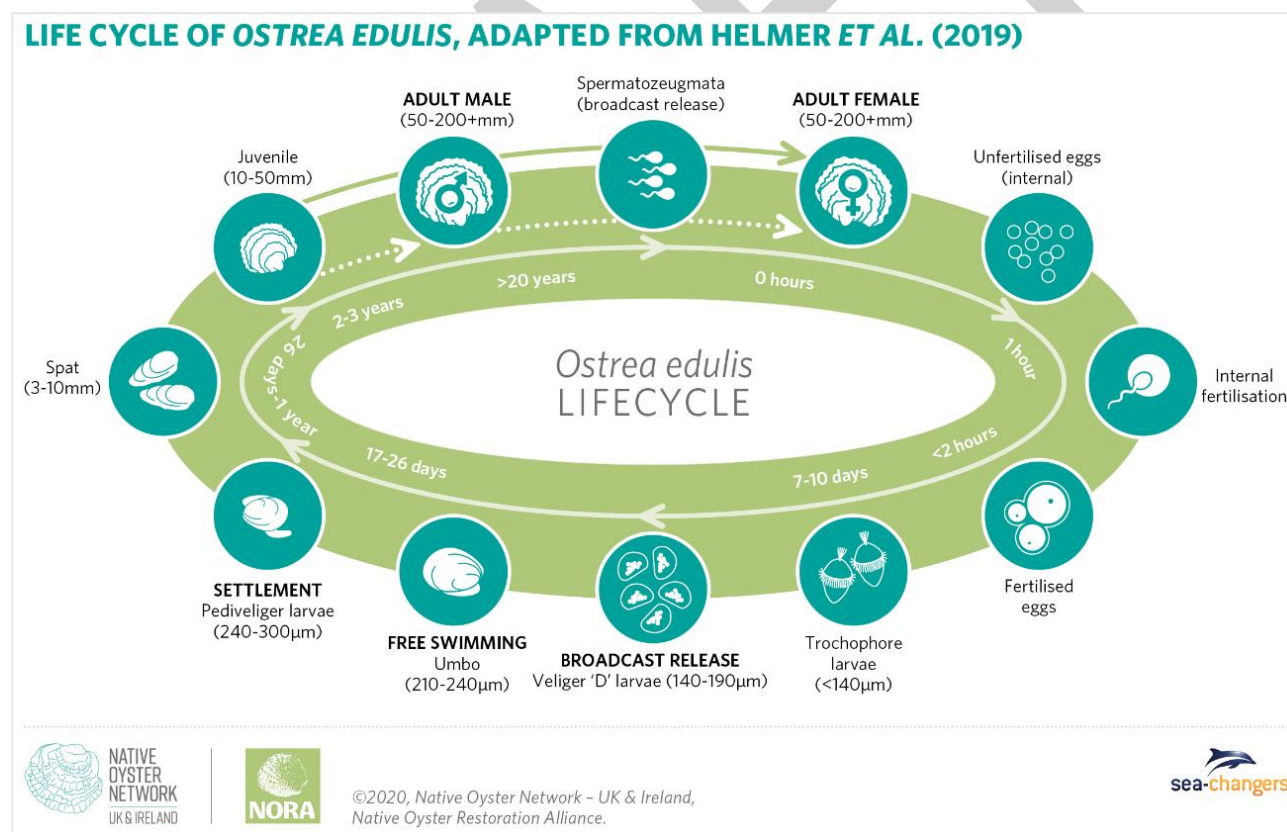


Figure 6. Native oyster lifecycle

Oyster restoration can be undertaken in several ways.

- Where there is an existing population, but habitat is poor, substrates such as shell or gravel, known as cultch, is introduced. Oyster spat require hard substrates on which to settle. They will preferentially settle on or in the vicinity of other living native oysters but will settle on alternative hard substrates with an established biofilm (Rodriguez-Perez *et al.*, 2019). Therefore, the placement of cultch aims to increase

settlement rates. There are strict biosecurity protocols required for the use of marine cultch, including heat and/or chemical treatment and a 12-month outdoor weathering period.

- Concentrating adult oysters within an area is a commonly used method of improving reproductive success. Broodstock nurseries are utilised by several projects in the UK (e.g. Wild Oysters). Cages filled with adult oyster are placed in areas where restoration is desired, often suspended from artificial structures such as existing marina pontoons. This method aims to increase the density of breeding adult oysters, that would otherwise be widely dispersed, to improve reproductive success.

In other projects, where populations are extinct or at extremely low densities, oysters are introduced either as juvenile seed or as adult broodstock.

- Seed oyster can be obtained in several different ways. They can be collected from naturally occurring spawning using sea-based collectors; floating/suspended structures that are put out to sea during the reproduction period (spring-summer) and rely on the natural settlement of spat. However, this only works where there is an existing population.
- Pond-based production involves the use of adult broodstock within contained or semi-contained ponds. Appropriate settlement media (cultch, spat collectors, limed tiles) is provided at the time of reproduction and the system is closed off to enable settlement of the larvae within the ponds. After settlement the spat can either be sold as clean spat or spat on shell, allowed to grow on to be sold as seed oyster, or put out to sea to grow on to be sold as larger oyster. In these ponds, fertiliser can be added to encourage algal production if required but in outdoor ponds is generally unnecessary.
- Hatchery production also involves the use of adult broodstock but typically includes a period of quarantine and conditioning prior to reproduction. This requires distinct periods of larval rearing, larval settlement and rearing of spat. Once established, spat or small seed oyster are moved into nursery tanks, often outdoors. In addition to specific facilities for each of these stages, there is a requirement to produce an algal food source for the oyster.

A summary of known oyster restoration projects currently being undertaken along the English coast are shown in Table 6. This is not an exhaustive list but provides an indication of the scale and restoration methods employed.

Table 6. Oyster restoration projects in England

Project	Organisation(s)	Location	Restoration Method	Restoration Target
<b>The Solent Oyster Restoration Project</b>	Blue Marine Foundation	Solent	Broodstock cages, Cultch, Research hatchery	n/a Aim is to create self-sustaining population
<b>Restoring biodiversity around the Humber Estuary</b>	Ørsted, Yorkshire Wildlife Trust, Lincolnshire Wildlife Trust	Humber Estuary	n/a	500,000 oyster
<b>Essex Native Oyster Restoration Initiative (ENORI)</b>	Multiple	Blackwater, Crouch, Roach and Colne Estuaries, Essex	Creation of 200ha 'mother oyster' sanctuary, Cultch and gravel laying	n/a Aim is to create a self-sustaining population capable of supporting a sustainable fishery

## 4.2 Existing UK Oyster Hatchery and Aquaculture Facilities

The primary oyster hatchery and aquaculture facilities in the UK are commercial suppliers and small-scale academic facilities. Many facilities have in the past focused on the growth of Pacific oyster, due to its value as a commercial aquaculture species, therefore facilities focusing specifically on native oyster are relatively rare.

### 4.2.1 Commercial Hatcheries

#### Morecambe Bay (Seasalter (Walney) Ltd)

Morecambe Bay Oyster/Seasalter (Walney) Ltd is a commercial oyster hatchery established in the 1980's as an extension of the Seasalter (Whitstable) Ltd hatchery. While the Kent facility originally produced native oyster to replenish the existing beds, production of both facilities focused on Pacific oyster, which have a higher commercial value and are easier to produce. Currently Seasalter (Walney) Ltd produces a small number of native oyster utilising the hatchery during the winter period when it is not being used for Pacific oyster.

The facility is located at the site of old gravel working lagoons in Morecambe Bay. The facility abstracts water directly from these lagoons to supply the indoor hatchery and outdoor nursery tanks. The site incorporates significant algae production facilities, consisting of 40 acres of lagoons managed for algae production, in addition to two blooming ponds and indoor algae production tanks (Figure 7). The water for the algae production tanks is pasteurised but otherwise the water supplied to the facility is not treated beyond the natural ground filtering as the lagoons are filled.

Currently within the hatchery there are two broodstock conditioning tanks which each hold 40 adult oyster, with conditioning phased so that both tanks do not reproduce at the same time. The spat are maintained in upwelling spat cylinders fed by a heated recirculating system and are gradually acclimatised to colder temperatures in preparation for moving out into the outdoor nursery tanks. Once in the outdoor nursery tanks the spat continue to grow until they are sold. At this site, the conditions are not suitable for the growing on of the native oysters in the open estuary. Whilst Pacific oysters can be readily grown in the estuary, the native oysters are less robust and suffer significant mortalities when exposed to large tidal range and storm conditions.

No information on set-up costs were available, but the facility is operated by three FTEs and at present only produces native oyster that can be sold. In 2022 approximately 2 million native seed oyster were produced. In previous years as many as 5 million have been produced but at that time there was no demand and the oyster were donated to a fishery.



Indoor algae production



Upwelling spat bottles



Outdoor nursery tanks

Figure 7. Photographs of the Seasalter (Walney) Ltd oyster hatchery. *Copyright Seasalter (Walney) Ltd/K. Thompson*

## Oyster Restoration Company

The Oyster Restoration Company have recently set-up a native oyster hatchery near Inverness, Scotland and has an established site on Orkney. Limited information is available on the set up of the facilities, however they have recently advertised the installation of nine large Industrial Plankton Inc. photobioreactors at the facility near Inverness. The company aims to produce 150 million biosecure native oysters per year to supply both the restoration and aquaculture markets<sup>9</sup>. Advancements have been made in collaboration with Xelect<sup>10</sup> in the use of genetic analysis for selective breeding, and in the use of eDNA to monitor disease status of the stock.

### 4.2.2 Project and Academic

#### Solent Oyster Hatchery – Portsmouth University

As part of the Solent Oyster Restoration Project, the Blue Marine Foundation in partnership with Portsmouth University set up the Solent Oyster Hatchery. This is a small-scale research hatchery within Portsmouth University that aims to produce 1 million oysters per year. Limited information is available on the detailed set-up of the facility, however it is known that filtered and UV sterilised seawater is used to supply multiple broodstock tanks which are also supplied with algae to encourage spawning. Facilities for larval treatment are unknown but spat are provided with oyster shell for settlement, which can then be put out on the restoration site.

Broodstock for the project were collected from the existing Solent population as part of mitigation for a cabling project, and under dispensation specifically for the hatchery.

The hatchery was established late in 2021 but produced no viable output in 2022. At the time of writing the hatchery is not operational due to lack of personnel. When in operation the hatchery was managed by a PhD student with support from interns, however, it was recommended that to run effectively two FTE would be required.

#### Fal Fishery Co-operative CIC

The Fal Fishery Co-operative CIC set up a native oyster restoration project (Saving Ester) in 2020 which, through crowd-funding, has been able to set up a microhatchery in a shipping container at Mylor Yacht

<sup>9</sup> <https://www.oysterrestorationcompany.co.uk/>

<sup>10</sup> <https://xselect-genetics.com/>

Harbour in Cornwall. Limited information is available about the set-up of the facility which appears to consist of a small number of holding tanks with a recirculating system. The hatchery has been established to aid trials and restoration activities specifically within the Fal oyster fishery, using broodstock from the existing population.

### 4.3 International Examples of Oyster Hatchery and Aquaculture Facilities

A review of *Ostrea edulis* hatcheries and pond producers across Atlantic Europe conducted by Kamermans *et al.* (2020) noted 19 facilities. Information is provided below for a small number of example facilities for which information was available.

#### Rossmore Oysters (Atlantic Shellfish Ltd.)

Rossmore Oysters is a commercial oyster supplier who utilises a series of artificial spatting ponds (each 30m x 30m x 2m, holding approximately one million litres of water) in Cork, Ireland to produce native oysters. The facility was established in the 1980s and after suffering high mortalities (98%) due to *Bonamia* parasite<sup>11</sup> and breeding only from the survivors, claims to have a population of *Bonamia* resistant native oysters.

The facility consists of 21 constructed, lined ponds into which seawater is pumped in spring/early summer and the ponds lined with cultch. Broodstock from the adjacent fishery population are then placed into the ponds (1,000 per pond) where they remain and spawn. After spawning, larvae settle onto the cultch within the pond where they remain for around 10 weeks until they reach approximately 5mm. This cultch is then transferred out to the seabed.

Temperature of the ponds is monitored, such that the onset of spawning can be predicted, but no specialist facilities are required for operation of the ponds. The water is not filtered or artificially adjusted. Once filled from the sea each pond is a closed system.

It is estimated that 10–20 million spat are produced by the ponds each year, with the commercial fishery selling up to one million adult oysters each year. The facility employs five FTEs. Set-up costs were not available however indicative costs for certain elements were provided, with each individual pond liner costing approximately £20,000 and the large seawater pump approximately £60,000. Rossmore Oysters currently only supply the seafood market with no intention of supplying the restoration market.

#### Helgoland Hatchery

Under the European PROCEED/RESTORE project a large-scale hatchery facility was set up to provide native seed oysters for restoration projects in the German Bight and to conduct research into optimal production and survival of native oyster. The facility covers 300m<sup>2</sup> within the Alfred Wegner Institute and consists of eight large (3,000 litre) outdoor quarantine tanks, 20 indoor 50 litre broodstock conditioning tanks, 36 indoor larval rearing tanks (30 x 5 litre and 6 x 250 litre), 18 indoor 500 litre settlement tanks and 18 outdoor 500 litre nursery tanks. In addition to the various hatchery tanks, algal production takes place in 36 indoor 500 litre tanks (Figure 8).

The hatchery has cost €1 million (~£880,400) to establish and employs five FTEs. The facility was established within an existing institute, taking advantage of existing infrastructure.

To date the facility has no measurable output.

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<sup>11</sup> Bonamiosis is a disease of the native oyster, *Ostrea edulis*, affecting both wild and cultivated stocks, and is caused by the infestation of a protozoan parasite, *Bonamia ostreae*.

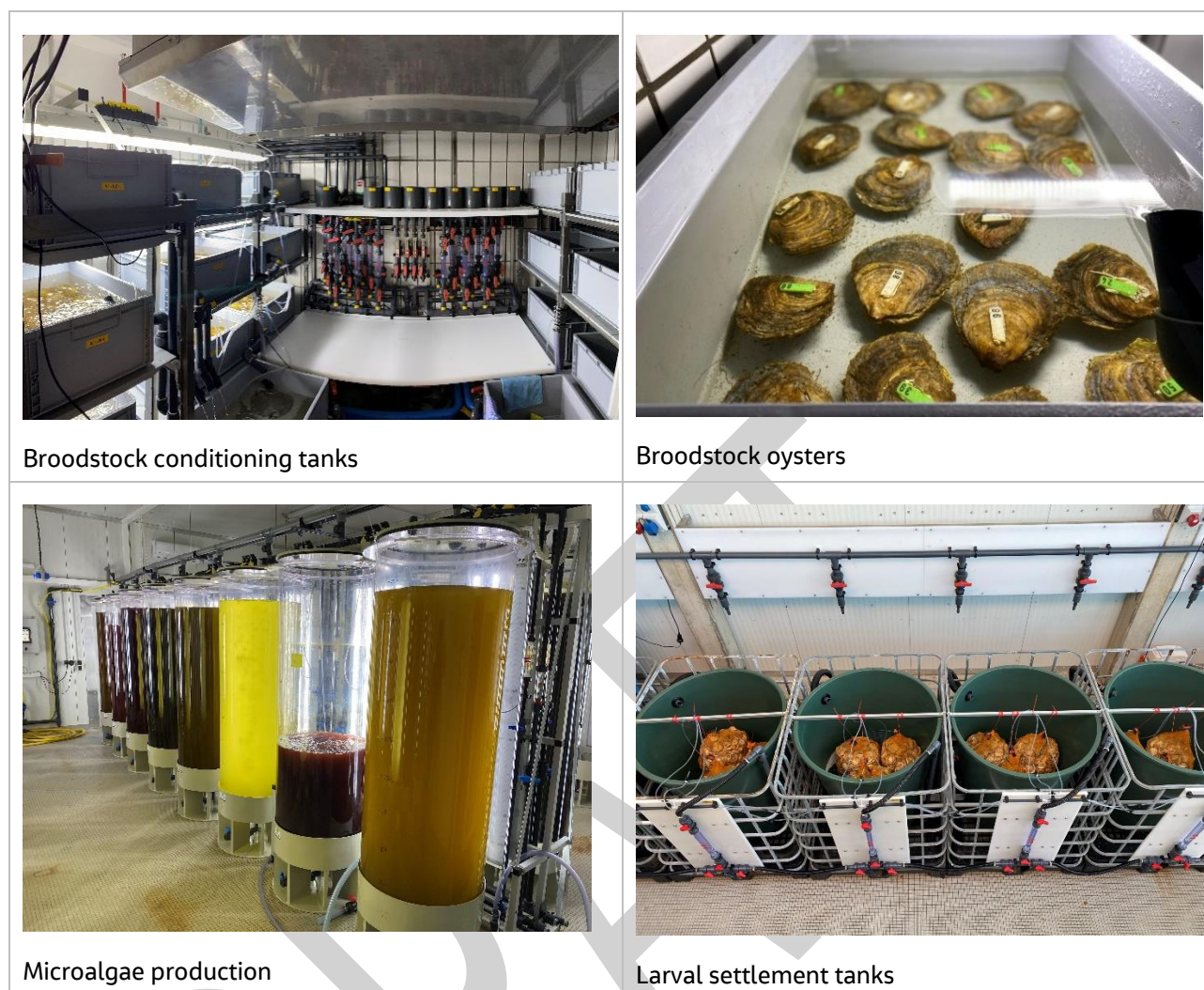


Figure 8. Photographs of Helgoland oyster hatchery. Copyright AWI/B.Colsoul 2023

## Danish Shellfish Hatchery<sup>12</sup>

In 2020/2021 a new large-scale multi-species hatchery was established, encompassing 750m<sup>2</sup> within the National Institute of Aquatic Resources (DTU Aqua). The facility uses filtered, UV-treated, recirculated and temperature controlled (5–25°C) seawater in a variety of recirculating and flow-through systems, with specific facilities for shellfish (including European oyster and lobster), microalgae and macroalgae production.

The dedicated European oyster hatchery room has an area of 187m<sup>2</sup> and includes 12 x 100 litre and 12 x 30 litre broodstock tanks, 40 x 15 litre larval tanks, 40 x 50 litre settlement and modular micro nursery tanks. The nursery is a separate 400m<sup>2</sup> building that is enclosed but not heated and is supplied with filtered seawater. In addition, the facility includes a 450m<sup>2</sup> raceway building with a set of 12 raceways and 10 upwelling tanks with filtered seawater that can be adjusted for 1 or 100µm. In each raceway there is room for 10 upwelling/downwelling containers with a volume of 55 litres.

Microalgae for oyster nourishment is grown in an 82m<sup>2</sup> production room fed by UV treated and 0.2µm filtered seawater. The room contains 10 x 100 litre photobioreactors and 72 x 50 litre batch culture bags. Four main microalgae strains are cultivated all year long as food sources (*Chaetoceros* sp., *Tisochrysis lutea*, *Pavlova gyrans* and *Rhodomonas salina*).

<sup>12</sup> <https://coast.dtu.dk/english/about/facilities-nykoebing/hatcheries-and-raceways>

Funding for the hatchery came from the Danish Finance Act for 2018, in which 30 million Danish Krone (approximately £3.5 million) was allocated over a four-year period to establish the first-large scale oyster hatchery in Denmark to support developments within sustainable exploitation of coastal natural resources in the form of oysters, other shellfish and seaweed.

### 4.4 Demand

The European Oyster Habitat Restoration Handbook (Preston *et al.*, 2020) notes that due to a lack of historical baseline data, target oyster densities should be project specific. The OSPAR Commission description for *Ostrea edulis* beds quotes densities of 5 or more per m<sup>2</sup>, this density has been used as a guide for determining potential demand.

The handbook gives guidance on required stocking densities for any given target density, which assumes a 5% retention. This figure was based upon observed retention in the Dornoch Firth in the north of Scotland, being restored by DEEP (Dornoch Environmental Enhancement Project). The project has a target of restoring 4ha of oyster habitat by introducing 4 million oysters, which, with a retention rate of 5%, equates to a target density of 5 per m<sup>2</sup>.

The ReMeMaRe restoration target of *at least* 15% by 2043 is not based on current extent of oyster beds and reefs, principally due to the scale of historic losses, with 15% of existing equating to just 1ha (hence the phrasing, '*at least*'). Instead, a more ambitious target of 100ha is considered by ReMeMaRe as a realistic representation of the desired scale of restoration. Therefore, at an established density of 5 oysters per m<sup>2</sup>, 100 million oysters would be required in the next 20 years.

The respondents of the online questionnaire and telephone interviews expressed the general opinion that oyster hatcheries and aquaculture facilities will be essential for native oyster restoration and the oyster restoration handbook states that increased production from hatcheries, local spatting ponds and collection of local wild spat is the long-term solution for oyster supply for restoration (Preston *et al.*, 2020).

The combined potential output of Seasalter (Walney) Ltd and the Oyster Restoration Company is claimed to be around 200 million native oyster spat each year. While there will be some competition with oyster farmers for supply, and neither facility is currently operating at this level of output, these suppliers could conceivably meet the required demand. The main considerations for relying on commercial suppliers are provision of sufficient lead-in time on orders, as it takes at least 12 months to produce seed oyster and the project requirement for single seed oyster, not spat on shell or larger oyster. Although not known for the Oyster Restoration Company, it is likely that both suppliers provide single seed oyster, not spat on shell or larger oyster.

### 4.5 Feasibility of Upscaling

#### 4.5.1 Output volume

The ability to meet restoration targets depends on the availability of broodstock and seed oysters. Several hatchery facilities have been established in the UK and Europe in recent years, however, success in the initial years has been limited and no significant outputs have been reported. It is therefore difficult to estimate hatchery output for a new facility. Commercial oyster suppliers have reported successful hatchery production of native oyster, however with limited demand in comparison to Pacific oyster, commercial suppliers are not incentivised to invest resource towards up-scaling production of native oysters.

A review of commercial oyster supply undertaken by Adamson *et al.* (2018) found that for Pacific oyster, UK suppliers had sufficient existing capacity to meet demand, even if one of them were to cease production. Seasalter (Walney) Ltd are confident that, if native oyster demand could be guaranteed, up to 50 million seed oyster could be produced per year, without any reduction in commercial Pacific oyster production. Some restoration practitioners are reluctant to obtain seed oyster from commercial suppliers who also produce non-native oyster, due to the potential of contamination of native oyster seed with Pacific oyster seed. These concerns could be alleviated with small changes to working practices and relatively minor investment to create two separate systems for the species (K Thompson 2023, personal communication, 27 February).

The intricacies of hatchery production and the significant input required to produce algae suggest that if further facilities are to be established, pond production systems, similar to those used by Rossmore Oyster,

may be a suitable approach. Rossmore oyster report average production of 0.5-1 million oyster spat from each 30m x 30m pond. For ease of calculation, it is therefore assumed that a 900m<sup>2</sup> pond could provide 0.75 million spat. A 15-pond system (1.5ha) could produce between 10 and 11 million oysters per year, meeting the required 100 million oyster target in 10 years.

Meeting restoration targets may be achieved using hatchery, pond-based production or both. A combination is recommended due to the ability of ponds to meet short to medium term demands while the hatchery facility develops. A combined facility would benefit from the relative ease and scale of pond production and the reduced seasonality of a hatchery facility. A similar arrangement/combination of production was proposed for the Swansea Bay Tidal Lagoon (Svyret *et al.*, 2017).

### 4.5.2 Location

The appropriate location for an oyster hatchery or aquaculture facility will depend on the type of facility to be developed. Hatcheries can make use of filtered and treated seawater systems to produce biosecure seed oyster. The use of isolated systems within one hatchery could enable stock from specific geographical locations to be kept separate.

Conversely the use of spatting ponds or growing-out areas involves exposure to natural conditions and seawater and therefore carries a high biosecurity risk. Therefore, spatting ponds can only be utilised in locations close to the recipient site as there is not currently a suitable protocol for making spat on shell biosecure for translocation between sites. Larger oyster can be subjected to rigorous cleaning and chemical treatments to make them suitable for translocation, but this is an extensive and labour-intensive process.

Currently several areas in the south of England (Devon and Cornwall; Dorset and Hampshire; Essex, Kent and Sussex) are classified as shellfish disease control areas for either *Bonamia* or oyster Herpes virus<sup>13</sup> and strict regulations on the movement of marine organisms into or out of these areas are in place. Therefore, the establishment of a national native oyster production facility in this location not considered appropriate. A large proportion of current oyster restoration projects are located in these areas but due to the presence of existing native oyster populations these projects are able to make use of restoration methods that rely on concentration of broodstock and habitat improvements or are able to introduce stock from disease-free sources. Spatting ponds could be a suitable means of increasing restoration stock in these areas.

With an existing commercial supplier, capable of producing large quantities of disease-free native oyster seed already located in the north west UK it would be logical, if a new hatchery facility is desired, to locate it in the north east, which correlates with the majority of potential native oyster restoration areas outside of the south and south east (Environment Agency, 2022).

### 4.5.3 Cost

Kamermans *et al.* (2020) present estimated costs for establishment and operating a native oyster hatchery producing 10 million spat (2mm) on shell. More than 75% of the €580,000 (~£510,000) set-up costs were associated with the building and algae production. Annual operational costs for such a facility, were estimated to be €531,656 (~£467,000). Both European oyster hatcheries described in Section 4.3 report funding of approximately €1 million (~£880,400) per year. In these cases, the hatchery is set up within an existing research facility taking advantage of existing infrastructure and limiting the cost and associated risk. Therefore, the establishment of a standalone hatchery facility may be significantly higher in terms of land acquisition, planning, infrastructure and permitting. An ROM cost estimation for a hatchery facility in the UK is in the range of £292,500 - £682,500 (excluding planning, permitting and associated infrastructure e.g. access tracks and utilities connections). A hatchery would employ up to 5 FTEs and would have high operating costs due to the algal production requirement which can account for over 30% of a facility's costs (Global Seafood Alliance, 2020). Information gathered by the questionnaire indicates that capital set-up and staffing account for 50 – 75% of costs with operation and maintenance accounting for only 10 – 25 %.

Pond facilities require significantly less investment in technology and algal production. A 15-pond system including an office/welfare building, and a large capacity pump, would have an ROM estimate for set-up costs in the range of £390,000 - £910,000 (excluding planning and permitting and associated infrastructure).

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<sup>13</sup> <https://www.gov.uk/guidance/prevent-fish-or-shellfish-diseases#control-areas-for-notifiable-disease-outbreaks>

Whilst comparable to set-up costs of a hatchery within an existing facility, the operating costs of a pond system would be relatively low. Although if shell cultch is to be used as settlement substrate this could incur a significant cost of up to £500 per tonne depending on source. Some projects, including ENORI, are working with the seafood market to establish a circular economy for the use of waste shell as cultch which may be a more economical route. This site would employ approximately 5 FTEs.

In addition to the establishment of new hatchery or pond-based facilities, consideration should be given to investing in existing facilities. In these instances, much of the equipment and infrastructure already exists, and relatively small investment can be made to secure an established, reliable supply of seed oyster. Where this is targeted towards commercial suppliers the primary investment would be in equipment which is difficult to make fully biosecure, such as hoppers and graders, or in the facilities to enable provision of spat on shell. Such investment is likely to be less than £100,000.

Investment in existing research hatcheries would differ depending on current facilities and potential for expansion. For example, the Portsmouth University hatchery is currently not operating due to lack of personnel (L Helmer 2023, personal communication, 27 February). Therefore, investment is likely to be in the form of 2-3 FTEs to keep the facility operating reliably. Such funding would be in the region of £100,00 - £150,000.

### 4.6 Oyster Summary and Conclusions

A comparison of potential options for upscaling oyster production is shown in Table 7.

In theory, demand can be met by existing commercial suppliers in the form of biosecure seed oyster. However, increased communication between the restoration sector and suppliers would be necessary as the long lead-in times make it hard to react quickly to changes in demand. This was recognised by the Native Oyster Restoration Alliance and led to production of two technical notes; one informing restoration practitioners about the oyster production industry (Strand *et al.*, 2021), and one informing the oyster production industry about oyster habitat restoration (zu Ermgassen *et al.*, 2021). A central system for restoration projects to record anticipated demand and specific requirements over the lifetime of their project, or for the next 2-3 years, would aid in this process. This is a system that could be hosted by the Native Oyster Network UK & Ireland, or NORA, and would allow not only a more reliable supply of native oyster but a way of tracking changes in demand as a proxy for restoration effort. This need not be restricted to demand for hatchery stock, but also where broodstock or spat on shell from particular locations are desired. Such a system could be established relatively quickly to assist with native oyster supply in the short-term and to give an indication as to where future investment would be most useful.

Establishment of a new oyster hatchery would be an expensive venture and evidence suggests that initial outputs will be unreliable. However, there are benefits associated with the ability to produce biosecure spat and perhaps greater control over genetics. The most logical approach for improved hatchery production would be through investment or collaboration with existing facilities. As discussed above, a relatively small investment could improve production from the Portsmouth University hatchery. Several other institutions located in the north east have similar facilities, such as Newcastle University (which already contains an algae culture lab<sup>14</sup>) and The Deep aquarium in Hull. Potential collaboration with these facilities could enable establishment of a hatchery facility with significantly reduced set-up costs and the added benefit of established education and research connections.

Issues with biosecurity make the use of stock from spatting ponds suitable only for introduction in the local area. Pond systems may be useful in areas of high restoration activity, such as the Kent and Essex estuaries. The Humber Estuary is currently receiving significant investment in restoration and is known to be sourcing seed oyster from commercial suppliers. If there is a desire to remove reliance on commercial suppliers, a system of spatting ponds could be established in the estuary with ability to supply restoration projects within the Humber and surrounding area.

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<sup>14</sup> <https://www.ncl.ac.uk/nes/about-us/facilities/marine/ridley-lab/>

**Table 7. Comparative analysis of the options for upscaling oyster production**

Option	ROM Set-up Cost	Operating Cost	FTEs	Annual Output	Restoration Potential	Benefits	Disadvantages
<b>Commercial suppliers</b>	n/a	n/a	n/a	>50 million spat	>50ha	<ul style="list-style-type: none"> <li>No initial outlay</li> <li>Established facility, process and skill set</li> <li>Relatively reliable output</li> <li>Biosecure seed oyster</li> </ul>	<ul style="list-style-type: none"> <li>Long lead-in time</li> <li>Limited control of source stock</li> <li>Cost tied to commercial value</li> <li>No research potential</li> <li>No direct job creation</li> <li>Limited availability of larger oyster or spat on shell</li> </ul>
<b>New hatchery</b>	£292,500 - £682,500	High	5	10 million spat	10ha	<ul style="list-style-type: none"> <li>Control of source stock</li> <li>Research opportunities</li> <li>Job creation</li> <li>Biosecure seed oyster</li> </ul>	<ul style="list-style-type: none"> <li>Significant investment</li> <li>Long establishment time</li> <li>Unreliable output</li> <li>Limited production of larger oyster or spat on shell</li> </ul>

Option	ROM Set-up Cost	Operating Cost	FTEs	Annual Output	Restoration Potential	Benefits	Disadvantages
<b>Investment in existing</b>	Unknown	Unknown	Unknown	Unknown	Unknown	<ul style="list-style-type: none"> <li>Reduced input relative to new hatchery</li> <li>Control of source stock</li> <li>Potential job creation</li> <li>Established facility</li> <li>Research opportunities</li> <li>Biosecure seed oyster</li> </ul>	<ul style="list-style-type: none"> <li>Unreliable output</li> <li>Limited production of larger oyster or spat on shell</li> <li>Limited by capacity and set-up of existing facility</li> <li>Risk tied to partner institution</li> </ul>
<b>Spatting ponds</b>	£390,000 - £910,000	Low/Moderate	5	10 million spat	10ha	<ul style="list-style-type: none"> <li>Established process</li> <li>Limited technology required</li> <li>No algal production necessary</li> <li>Job creation</li> <li>Potential circular economy related to use of shell cultch</li> </ul>	<ul style="list-style-type: none"> <li>Not biosecure so limited use</li> <li>Significant initial investment</li> <li>Output reliant on environmental conditions</li> <li>Limited research opportunities</li> </ul>

## 5. Combined Facilities

### 5.1 The Concept

Common themes connect the facility requirements for both seagrass and oyster facilities and to a lesser extent saltmarsh; the need for a seawater supply, biosecurity concerns, the benefits of being situated in the same locale as the restoration sites, and the applicability of both indoor and outdoor facilities. Taking account of these factors, it would seem reasonable to consider establishment of coastal hubs, integrating indoor labs, polytunnels and outdoor ponds. These facilities could incorporate several species either in isolation or in trial combinations. For instance, both seagrass nursery operators who were contacted noted an issue with algal blooms in the seagrass tanks. Whereas oyster producers put significant effort into production of algae. While the species of algae are carefully controlled for oyster growth, the possibilities and potential benefits of multi-species aquaculture have been reported (Meng *et al.*, 2019, Sandoval-Gil *et al.*, 2016). With a movement towards seascape restoration, the logical approach is the creation of 'seascape hubs'.

### 5.2 UK Examples

The idea of hubs is not a new concept. In 2017, Goodwin *et al.* prepared a feasibility report into the development of a similar facility at the site of the former AstraZeneca site in Brixton and suggested significant benefits in development of an environment hub in comparison to a stand-alone fisheries and aquaculture lab facility.

A proposal has been made for such a facility on the west coast of Ireland, Páirc na Mara. Although still in the planning stages, this marine innovation hub intends to provide facilities including a research and development centre, boat building centre, seaweed added value facility, shellfish spatting ponds, aquaponics facility and blast freezer unit. Although targeting predominantly innovation in the commercial sector and a wider range of processes, a facility such as Páirc na Mara demonstrates how a hub could benefit more than one targeted feature providing efficiencies and opportunities.

### 5.3 International Examples of Combined Facilities

The Cawthron Aquaculture Park<sup>15</sup> in New Zealand is a world-class research and technology centre for the New Zealand aquaculture sector and its stakeholders. It's a shared facility, purpose-built for aquaculture research, education and commercial development. The park is situated on a 20ha site with facilities including wet labs, dry labs, algal culture facilities and outdoor ponds. The facilities at the park are available for lease and host aquaculture industry firms, teaching labs and their own research group. The park also incorporates the Finfish Research Centre and National Algae Research Centre, a hub of innovation and knowledge to support the establishment of New Zealand's seaweed industry.

The Mote Aquaculture Park, Florida is a research and innovation centre focused on the development of sustainable aquaculture technology. As well as hosting the Florida red tide mitigation & technology development facility and the International Coral Gene Bank, the park contains multiple aquaculture research facilities. The aquaculture facility comprises 15 acres of buildings within a 200 acre site, recirculating 100% of their seawater, as they are based more than 20 miles from the nearest large waterbody. In addition to pilot and commercial scale aquaculture facilities, the park includes an aquaponics centre raising fish and plants together in a closed loop system.

The Aquaculture Research Station at the Institute for the Sea and Atmosphere (EPPO-IPMA)<sup>16</sup> is a public research facility located at the Natural Park of the Ria Formosa, Portugal, carrying out production studies from bench top to large semi-industrial scale. The facility consists of more than 260 tanks of various sizes and set-ups and 17 large outdoor ponds. The onsite buildings contain a number of temperature-controlled rooms and algal growing facilities.

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<sup>15</sup> <https://www.cawthron.org.nz/our-research/our-resources/>

<sup>16</sup> <https://aquaexcel.eu/ccmar-labs-and-platforms/>

## 5.4 Potential Facility

### 5.4.1 Output

Required output would be dependent on location (see Section 5.4.2). Large-scale oyster, seagrass and saltmarsh production is likely to rely on the more 'agricultural' production methods but could incorporate smaller indoor facilities for research or educational activities.

An example facility could include:

- a small system of spatting ponds. Five x 900m<sup>2</sup> ponds could produce up to 3.75 million seed oyster per year;
- a number of shallower outdoor ponds (1,000m<sup>2</sup>) for growth of saltmarsh and seagrass (if this method of growth is shown to be successful). Ten ponds could potentially produce up to 1 million plants (either saltmarsh or seagrass or a combination);
- large polytunnels for germination of saltmarsh and seagrass seedlings. Each 500m<sup>2</sup> of polytunnel could produce up to 50,000 saltmarsh seedlings, or could contain ponds producing 5,000-10,000 seagrass plants or up to 750 seedling mats;
- seed processing/storage area within an industrial style site building. A 150m<sup>2</sup> building with 30 tanks could process up to five million seagrass seeds and an insulated storage container with chiller and recirculating system could be used for seed storage;
- site buildings containing office/welfare facilities and wet lab facilities that can be utilised primarily for small-scale research, broodstock storage (quarantine, conditioning, etc) and educational and outreach activities. These indoor lab facilities are unlikely to contribute significantly to output; and
- an outdoor area designated for weathering of cultch and potential composting of seagrass material.

At the values described above, this would equate to approximate annual restoration potential of:

- 16.3ha saltmarsh;
- 15ha seagrass (8ha seed bags, 5.6ha seedling mats, 2ha planting); and
- 3.75ha oyster habitat.

One benefit of such a site would be the ability to repurpose facilities depending on requirements at any given time or a particular location. For example, ponds can be used to hold plant material during seed processing, or greenhouse pond could be used as oyster nursery ponds or for algal production if required for broodstock or if a small-scale hatchery is incorporated in the wet lab.

### 5.4.2 Location

A single hub to meet national demand is unlikely to be feasible. Using current production methods, the site would be a significant size and would do little to address the biosecurity issues related to movement of material from one location to another.

Therefore, a network of smaller regional hubs around the country would be more appropriate. Exact locations would be determined by availability of suitable sites but to provide suitable coverage it would be realistic to propose one site on the west coast, one site on the east coast, one in the south east and one site on the south coast. Although based in Wales, the Pendine site has the ability to supply the south west and presents an opportunity for collaboration at an existing site.

### 5.4.3 Cost

The initial development of each seascape hub is likely to require significant investment but would provide multiple facilities at each site.

Each site is likely to be between 4-5ha in size with associated land purchase cost of around £82,500 - £192,500. An ROM estimate for construction of ponds and polytunnels and seagrass processing and storage would be in the range of £470,550 - £1.1 million (assuming 15 ponds and 2,500m<sup>2</sup> polytunnel). The cost of a welfare and lab building will be dependent on the size and type of building but a cost of £382,500 - £892,500 is considered a reasonable estimation.

An ROM estimate for the construction of a seascape hub is therefore in the range of £928,050 - £2.16 million, excluding planning, permitting or associated infrastructure.

A site of this size is likely to require in the region of 25-30 FTEs when operating at full capacity adding almost £1 million to the annual operating costs which would otherwise be moderate and dependent on how the facility was configured.

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**Table 8. Analysis of seascape hub option**

Option	ROM Set-up Cost	Operating Cost	FTEs	Example Annual Output	Example Annual Restoration Potential	Benefits	Disadvantages
<b>Seascape hub</b>	£928,050 - £2.16 million	Moderate	25-30	3.75 million oyster spat 978,000 saltmarsh plants 80,000 seed bags 2,240 seedling mats 10,000 seagrass plants	3.75ha oyster bed 16.3ha saltmarsh 15ha seagrass	<ul style="list-style-type: none"> <li>Job creation</li> <li>Spread of risk across multiple features</li> <li>Facility can be adapted to meet changes in demand</li> <li>Research opportunities</li> <li>Volunteering opportunities</li> <li>Education/outreach opportunities</li> <li>Opportunities for circular economy with seagrass and cultch.</li> </ul>	<ul style="list-style-type: none"> <li>Significant investment</li> <li>Multiple sites required to meet restoration demand</li> <li>Large physical footprint</li> </ul>

## 6. Overall Conclusions and Recommendations

Presently, saltmarsh restoration relies predominantly on natural regeneration after creation of suitable conditions, however seagrass and oyster restoration is subject to more active intervention including the introduction of seagrass or oyster 'stock'. The ability to meet ReMeMaRe restoration targets for seagrass and native oyster in England is at risk due to a lack of successful large-scale restoration methods. Current seagrass and oyster restoration techniques are labour intensive and suited to relatively small-scale projects. There is a decision to be made regarding the establishment of further facilities and whether there should be a focus on research of improved production/restoration techniques, or a focus on large-scale production of seagrass and oyster using existing techniques, to supply a greater number and size of projects utilising existing restoration methods. The establishment of high-tech innovative lab and hatchery facilities is expensive and currently shows limited success in the ability to reliably provide large output, however these facilities are undoubtedly contributing to the progression of restoration research. Conversely, more 'agricultural' facilities utilising polytunnels and ponds are showing promising ability to reliably produce output at scale but are perhaps less attractive in terms of progressive research.

The study has shown that upscaling of saltmarsh nursery facilities is unlikely to be necessary at this time due to low demand, presence of existing suppliers and the ability to establish a small-scale project specific facilities relatively quickly and at low cost. However, if practices change, with planting becoming more commonplace, significant upscaling of saltmarsh nurseries would be required.

Current seagrass restoration methods and facilities are not sufficient to meet restoration targets. Existing facilities are project specific, predominantly conducting trials and fully committed supplying a few small-scale projects. Adaptation of restoration methods and upscaling of facilities will be required. Current evidence suggests that different restoration strategies will be more successful at different restoration sites (Croneau *et al.* 2023) therefore the best approach will be facilities that can process and store a large quantity of seeds but that can also germinate and grow seagrass seedlings. To be able to continue to contribute to and react to progressing research in seagrass restoration, a facility with a combination of indoor, outdoor and polytunnel facilities is recommended. Having these facilities based in the south east and north west of England would enable production to be focuses in areas with the greatest seagrass restoration potential

The need for native oyster production facilities is somewhat less clear. Current commercial hatcheries claim to have capacity to meet demands for restoration but, due irregular demand, do not currently focus significant effort into the native species. Additionally, a new large-scale native oyster hatchery is being developed in north west Scotland, which aims to make a significant contribution to restoration and commercial supply, but is as yet not thought to be in operation.

If a reliance on commercially produced seed oyster is not desired, then two options exist for increased production; investment in existing facilities and use of regional spatting ponds. The cost of creating a new stand-alone hatchery facility and the risk associated with poor success of newly established hatcheries is considered to make this an undesirable option. Investment in existing hatcheries and development of hatchery facilities within existing institutions would enable greater control over supply and the ability to contribute to research. However, depending on the existing facilities the scale of investment could be relatively large and output unreliable. The use of spatting ponds is a low-tech alternative to hatcheries, but production is reliant on environmental conditions and the inability to produce a biosecure product make them suitable only in areas close to the recipient site.

With increasing focus on 'seascape' restoration and the multiple shared requirements of coastal aquaculture and nursery facilities, it is appropriate to consider establishment of a shared facility or hub rather than individual facilities. Development of a seascape hub containing a variety of indoor lab-based facilities, polytunnels and outdoor ponds would enable large-scale production of seagrass, oyster and saltmarsh if required. The investment in a single such site would be significant and multiple smaller sites would be advised, however in sharing facilities, set-up costs (land acquisition, planning and permitting, infrastructure) can be shared. In addition to financial benefits, seascape hubs allow production to be somewhat tailored to the specific demand at any given time, with most facilities having use for multiple features. Such sites also provides opportunity for research into multi-species production and the interactions between these coastal features. Educational and outreach activities are potentially more appealing in a multi-function facility like the proposed seascape hubs, making them more desirable to the local community than single habitat/species facilities.

Regional seascape hubs are considered to be the most logical approach to upscaling nursery and aquaculture facilities for restoration. They are, however, not a standalone measure and efforts should continue into researching more effective restoration techniques in addition to continued use of methods that do not require input of stock.

During the course of this study a number of factors have come to light that are worthy of further consideration.

The first of these is production of a central digital tool for tracking restoration demand. This could be broken down into individual habitats and hosted by the relevant focus group, such as the Native Oyster Network, or by ReMeMaRe. The success of the system would rely on individual projects inputting their anticipated demand at least 1 year in advance and consideration would have to be given as to how much information was available to suppliers. However, if utilised correctly this could be a useful and important tool in ensuring sufficient stock for restoration.

Further research into the potential for collaborative facilities is required. This would involve identification of existing facilities or institutions willing to house a restoration facility or identification of partners (commercial or research) who have an interest in shared ownership of a facility.

Further research into the potential for multi-species aquaculture should be undertaken. Significant space saving benefits could be achieved if for instance, oyster and saltmarsh can be produced in the same pond. This could form one of the research focuses of a proposed new facility.

If future approaches to saltmarsh restoration shift to planting rather than natural colonisation and demand for saltmarsh plants increases to anywhere near the potential levels (>10 million plants per year), the use of vertical farming towers could be explored to enable greater numbers of plants to be produced in a more space efficient way.

There are also wider potential economic benefits from this restoration work, in line with Government policies and objectives. The UK is committed to moving towards a more circular economy<sup>17</sup> which could align with certain aspects of this work e.g. discarded oyster shells from commercial use being reused as cultch in some of the facilities described in this report. The UK has also shown interest in innovative approaches to the "Blue Economy", which describes potentially untapped economic benefits (and challenges) relating to seas and oceans<sup>18</sup>.

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<sup>17</sup> <https://www.gov.uk/government/publications/circular-economy-package-policy-statement/circular-economy-package-policy-statement>

<sup>18</sup> <https://www.gov.uk/government/news/ukho-launches-new-innovation-programme-to-support-development-of-the-blue-economy>

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## Appendix A. Online Questionnaire

The following questionnaire was sent out to ReMeMaRe partners, restoration project personnel, researchers, nursery, aquaculture and shellfishery facilities managers and suppliers.

### Section 1 - Feature of Interest

#### 1. Name and Project/Organisation

#### 2. Which feature is your project/facility associated with?

- Oyster
- Seagrass
- Saltmarsh
- Other

### Section 2 – Project Related

#### 3. Which method(s) of restoration do you utilise?

- Natural regeneration
- Direct transplant from nearby donor site
- Collection of material from nearby site with local processing/propagation before transplant
- Other

#### 4. What is your estimated success rate for the methods used above?

#### 5. What is your estimated success rate for the methods used above?

- The feature has proven ability to naturally regenerate when provided with suitable conditions
- There are limited or no local natural sources or donor populations (or collection would result in unacceptable damage to donor populations)
- External suppliers of source stock are readily available and reliable
- External suppliers of source stock are rare or unreliable
- Concerns over local genetics (attempting to maintain local genetic types or increasing gene pool of depleted population)
- Biosecurity concerns over introducing stock

- Cost
- Timeframe
- Other

6. What area of habitat have you already restored? What is your overall restoration target area?

7. How much source material (i.e. seeds, spat) do you need/use per unit area?

8. What is the indicative cost in relation to restocking/replanting per unit area restored?

### Section 3 – Facility Related

9. Describe the facility/set-up you operate (e.g. academic lab, poly tunnel, outdoor spatting ponds, including size)

10. Does your facility have specific requirements (e.g. seawater supply, special lighting)?

11. Is your source material:

- Broodstock/established plants from wild population
- Seed/spat from wild population
- Self sustaining facility population

Other

**12. What is your main output?**

- Spat
- Juvenile oyster
- Adult oyster
- Seeds
- Seedlings
- Plug plants
- Other

**13. What is your current output (e.g. volume of cultch/spat, seeds/seedlings)? If this does not represent the maximum potential output of your existing facility, what is your estimated potential maximum output?**

**14. Do you take into consideration the location of the receiving project and utilise local donor stock? Can you process/propagate separate populations from multiple different locations at one time?**

**15. Could your existing facility be adapted for greater output or to process/propagate additional features?**

**16. How is your facility funded?**

- Commercial
- Project
- Charity / Trust
- Other

17. If commercial, what proportion of your facility/output is related to supplying restoration projects?

18. If project funded do you share your facility with other projects? If so is it shared with other projects related to a different feature (e.g. if your project is related to oyster do you share your facility with projects related to seagrass)?

19. If project funded, what will happen to your facility at the end of the project/funding?

20. How many full-time (equivalent) personnel (including volunteers) does it take to operate the facility?

21. Do you make use of volunteers in your facility (not including volunteers undertaking subsequent transplanting)? If so, how many?

22. What is the total annual cost of your facility

23. What proportion of your costs are related to

	<10%	10-25%	25-50%	50-75%	75-90%	>90%
Capital set up	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Staffing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Operation / maintenance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Regulation / compliance / biosecurity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

24. What is your approximate facility cost per unit output?

25. What is your average cost to transport per unit output? Does this vary significantly depending on project location?

26. Do you have any further information or views on the use of aquaculture and/or nursery facilities for restoration projects and whether existing facilities are adequate to meet the demands of large-scale restoration?

27. Please indicate whether you are happy to be contacted to discuss your project/facility further.

Yes

No

## Appendix B. Breakdown of Rough Order of Magnitude Costs

### B.1 Source Costs

A variety of sources were used to estimate ROM costs including information provided by study participants, online retailers, online guidance and best estimates. Where values are specific to system set up (e.g. pumps, filters, tanks) a nominal value has been used throughout. Salary for FTEs was taken as the average provided by the National Careers Service for a biologist<sup>19</sup>.

### B.2 Saltmarsh Facilities

Large pond-based nursery

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 1 million plug plants
Land	£10,000 / acre	2.5ha	£60,000
Welfare/office building	£25,000	1 portable building	£25,000
Site storage	£5,000	1 container	£5,000
Pumps and filters	£10,000		£10,000
Pond materials plus groundworks	£25,000	10 ponds	£250,000
<b>Facility total</b>			<b>£290,000</b>
Staff	£33,000	10 FTE	£330,000

### B.3 Seagrass Facilities

Seagrass seed processing

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 20 million seeds per annum
Land	10,000 / acre	0.5 acre	5000
Industrial style building with welfare facilities	£400 - £900 / m <sup>2</sup>	300m <sup>2</sup>	£180,000
IBC tanks	£250 per tank	100 tanks	£25,000
Water storage tanks	£4,000 (30,000 litres)	Assume storage required to approximately match	£8,000

<sup>19</sup> <https://nationalcareers.service.gov.uk/job-profiles/biologist>

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 20 million seeds per annum
		half of total IBC tank capacity	
Pumps, filters and pipework			£20,000
<b>Facility Total</b>			<b>£238,000</b>
Staff	£33,000	Assume 0.75 staff per 10 tanks due to seasonal nature of operation	£247,500

### Seagrass seed storage

Item	Unit Cost	Volume/Quantity Assumptions	Cost to store 20 million seeds per annum
Insulated container	£10,000-15,000	40 ft (12m container)	£10,000
Water chiller and pump	£2,000		£2,000
Small seed storage tanks/troughs	£50 / 18m	400m x 10cm drainpipe	£1,200
Artificial sea water	£1700 / 1,000 litres	1000 litres in recirculating system	£1,700
<b>Facility total</b>			<b>£14,900</b>
Staff	£33,000	0	£0

### Lab-based seagrass seedling mat growth

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 15,000 seedling mats per year
Land	10,000 / acre	0.5 acre	£5,000
Industrial style lab building	£400 - £900 / m <sup>2</sup>	800m <sup>2</sup>	£480,000
Seawater treatment (sand filters and chemical/UV filters)			£10,000
Aquarium lighting	£225 / m <sup>2</sup>	2000m <sup>2</sup>	£450,000

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 15,000 seedling mats per year
Water pumps & pipework			£10,000
Water heater/chiller			£20,000
Tanks and associated furniture	£100 / m <sup>2</sup>	5000m <sup>2</sup>	£200,000
<b>Facility total</b>			<b>£1,175,000</b>
Staff	£33,000	20 - 30	£660,000 - £990,000

#### Polytunnel-based seagrass seedling mat growth

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 15,000 seedling mats per year
Land	£10,000 / acre	2 acres	£20,000
Welfare building	£25,000	1 portable building	£25,000
Site storage	£5,000	2 containers	£10,000
Large polytunnel	£28 / m <sup>2</sup>	9,800m <sup>2</sup>	£274,400
Pumps and filters			£10,000
Pond materials	£40 / m <sup>2</sup>	4,900m <sup>2</sup>	£196,000
Pond vacuum	£500	3	£1,500
<b>Facility Total</b>			<b>£536,900</b>
Staff	£33,000	15 FTES (20-30 seasonal)	£495,000

#### Polytunnel-based individual plant growth

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 15,000 seedling mats per year
Land	£10,000 / acre	5.5 acres	£55,000
Welfare building	£25,000	4 portable buildings	£100,000

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 15,000 seedling mats per year
Site storage	£5,000	2 containers	£10,000
Large polytunnel	£28 / m <sup>2</sup>	20,300m <sup>2</sup>	£568,400
Pumps and filters			£10,000
Pond materials	£40 / m <sup>2</sup>	12,200m <sup>2</sup>	£488,000
Pond vacuum	£500	10	£5,000
<b>Facility total</b>			<b>£1,236,400</b>
Staff	£33,000	100	£3,300,000

#### Outdoor pond-based seagrass growth

As there are no case studies to use, an assumption has been made that a 100m<sup>2</sup> pond could produce 90 seedling mats per year.

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 250,000 seedling mats
Land	£10,000 / acre	1.5ha	£35,000
Welfare building	£25,000	1 portable building	£25,000
Site storage	£5,000	2 containers	£10,000
Pond materials and groundworks	£25,000	5 ponds	£125,000
Water pump			£10,000
<b>Facility total</b>			<b>£205,000</b>
Staff	£33,000	10	£330,000

#### Combined seagrass facility

Item	Unit Cost	Volume/Quantity Assumptions	
Land	£10,000 / acre	1 acre	£10,000
Industrial style building	£400-900 / m <sup>2</sup>	£300m <sup>2</sup>	£180,000

Item	Unit Cost	Volume/Quantity Assumptions	
IBC tanks	£250	50	£12,500
Seed storage			£14,900
Artificial lighting	£225 / m <sup>2</sup>	200m <sup>2</sup>	£45,000
Water heater/chiller			£20,000
Filters and pumps			£10,000
Polytunnels	£28 / m <sup>2</sup>	2,400m <sup>2</sup>	£67,200
Pond materials	£40 / m <sup>2</sup>	1,200m <sup>2</sup>	£48,000
Water storage		30,000 litres	£4,000
Tanks and associated furniture	£100 / m <sup>2</sup>	200m <sup>2</sup>	£20,000
<b>Facility total</b>			<b>£431,600</b>
Staff	£33,000	10 - 15	£330,000 – £495,000

## B.4 Oyster Facilities

### Oyster hatchery

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 10 million seed oyster per year
Land	£10,000 / acre	1 acre / 0.4ha	£10,000
Industrial style lab building including welfare facilities	£400 - £900 / m <sup>2</sup>	300m <sup>2</sup>	£180,000
Seawater treatment (sand filters and chemical/UV filters)			£10,000
Water pumps & pipework			£10,000
Water heater/chiller			£20,000
Tanks and associated furniture			£10,000

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 10 million seed oyster per year
Algal production (photobioreactors)			£150,000
<b>Facility Total</b>			<b>£390,000</b>
Staff	£33,000	3	£99,000

### Pond-based oyster production

Item	Unit Cost	Volume/Quantity Assumptions	Cost to produce 10 million seed oyster per year
Land	£10,000 / acre	5 acres / 2ha	£50,000
Welfare building	£25,000	1 Portable building	£30,000
Site storage	£5,000	2 containers	£10,000
Pond materials & groundworks	£25,000	15 ponds	£375,000
Water pump			£60,000
<b>Facility Total</b>			<b>£520,000</b>
Staff	£33,000	5	£165,000

## B.5 Seascope Hub

Item	Unit Cost	Volume/Quantity Assumptions	
Land	£10,000 / acre	10 – 12 acres	£110,000
Pond materials and ground works	£25,000	15 ponds	£375,000
Large polytunnels	£28 / m <sup>2</sup>	2,500m <sup>2</sup>	£70,000
Indoor pond materials/growing trays	£40 / m <sup>2</sup>	1,500m <sup>2</sup>	£60,000
Industrial style building	£400 - £900 / m <sup>2</sup>	150m <sup>2</sup>	£90,000

Item	Unit Cost	Volume/Quantity Assumptions	
IBC tanks	£250	30	£7,500
Pumps, filters, etc			£10,000
Seed storage			£14,900
Site building	£2,500 / m <sup>2</sup>	200m <sup>2</sup>	£500,000
Tanks and associated furniture	£100 / m <sup>2</sup>	100m <sup>2</sup>	£10,000
<b>Facility total</b>			<b>£1,237,400</b>
Staff	£33,000	25-30	£891,000

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